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SUMMARY TECHNICAL REPORT

OF THE

NATIONAL DEFENSE RESEARCH COMMITTEE

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SUMMARY TECHNICAL REPORT OF DIVISION 12, NDRC

VOLUME 1

TRANSPORTATION EQUIPMENT AND RELATED PROBLEMS

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT
VANNEVAR BUSH, DIRECTOR

NATIONAL DEFENSE RESEARCH COMMITTEE
JAMES B CONANT, CHAIRMAN

DIVISION 12
HARTLEY ROWE, CHIEF

WASHINGTON, D. C., 1946

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NOTES ON THE ORGANIZATION OF NDRC

The duties of the National Defense Research Committee were (1) to recommend to the Director of OSRD suitable projects and research programs on the instrumentalities of warfare, together with contract facilities for carrying out these projects and programs, and (2) to administer the technical and scientific work of the contracts. More specifically, NDRC functioned by initiating research projects on requests from the Army or the Navy, or on requests from an allied government transmitted through the Liaison Office of OSRD, or on its own considered initiative as a result of the experience of its members. Proposals prepared by the Division, Panel, or Committee for research contracts for performance of the work involved in such projects were first reviewed by NDRC, and if approved, recommended to the Director of OSRD. Upon approval of a proposal by the Director, a contract permitting maximum flexibility of scientific effort was arranged. The business aspects of the contract, including such matters as materials, clearances, vouchers, patents, priorities, legal matters, and administration of patent matters were handled by the Executive Secretary of OSRD.

Originally NDRC administered its work through five divisions, each headed by one of the NDRC members. These were:

Division A	Armor and Ordnance
Division B	Bombs, Fuels, Gases, & Chemical Problems
Division C	Communication and Transportation
Division D	Detection, Controls, and Instruments
Division E	Patents and Inventions

In a reorganization in the fall of 1942, twenty-three administrative divisions, panels, or committees were created, each with a chief selected on the basis of his outstanding work in the particular field. The NDRC members then became a reviewing and advisory group to the Director of OSRD. The final organization was as follows:

Division 1	Ballistic Research
Division 2	Effects of Impact and Explosion
Division 3	Rocket Ordnance
Division 4	Ordnance Accessories
Division 5	New Missiles
Division 6	Sub-Surface Warfare
Division 7	Fire Control
Division 8	Explosives
Division 9	Chemistry
Division 10	Absorbents and Aerosols
Division 11	Chemical Engineering
Division 12	Transportation
Division 13	Electrical Communication
Division 14	Radar
Division 15	Radio Coordination
Division 16	Optics and Camouflage
Division 17	Physics
Division 18	War Metallurgy
Division 19	Miscellaneous

Applied Mathematics Panel
Applied Psychology Panel
Committee on Propagation
Tropical Deterioration Administrative Committee

NDRC FOREWORD

As events of the years preceding 1940 revealed more and more clearly the seriousness of the world situation, many scientists in this country came to realize the need of organizing scientific research for service in a national emergency. Recommendations which they made to the White House were given careful and sympathetic attention, and as a result the National Defense Research Committee [NDRC] was formed by Executive Order of the President in the summer of 1940. The members of NDRC, appointed by the President, were instructed to supplement the work of the Army and the Navy in the development of the instrumentalities of war. A year later, upon the establishment of the Office of Scientific Research and Development [OSRD], NDRC became one of its units.

The Summary Technical Report of NDRC is a conscientious effort on the part of NDRC to summarize and evaluate its work and to present it in a useful and permanent form. It comprises some seventy volumes broken into groups corresponding to the NDRC Divisions, Panels, and Committees.

The Summary Technical Report of each Division, Panel, or Committee is an integral survey of the work of that group. The first volume of each group's report contains a summary of the report, stating the problems presented and the philosophy of attacking them, and summarizing the results of the research, development, and training activities undertaken. Some volumes may be "state of the art" treatises covering subjects to which various research groups have contributed information. Others may contain descriptions of devices developed in the laboratories. A master index of all these divisional, panel, and committee reports which together constitute the Summary Technical Report of NDRC is contained in a separate volume, which also includes the index of a microfilm record of pertinent technical laboratory reports and reference material.

Some of the NDRC-sponsored researches which had been declassified by the end of 1945 were of sufficient popular interest that it was found desirable to report them in the form of monographs, such as the series on radar by Division 14 and the monograph on sampling inspection by the Applied Mathematics Panel. Since the material treated in them is not duplicated in the Summary Technical Report of NDRC, the monographs are an important part of the story of these aspects of NDRC research.

In contrast to the information on radar, which is of widespread interest and much of which is released to the public, the research on subsurface warfare is largely classified and is of general interest to a more restricted group. As a consequence, the report of Division 6 is found almost entirely in its Summary Technical Report, which runs to over twenty volumes. The extent of the work of a division cannot therefore be judged solely by the number of volumes devoted to it in the Summary Technical Report of NDRC: account must be taken of the monographs and available reports published elsewhere.

Division 12 was one of the smallest divisions of NDRC, but its accomplishments were far out of proportion to its size and its impact on the conduct of the war was of major significance. Battle reports from Normandy to Okinawa attest to the value of its contributions to the concept and the implementation of amphibious logistics and of the amphibious assault. These reports serve likewise as testimonials to the vision, the intense personal devotion, and the integrity of Hartley L. Rowe, Chief of the Division, and of the men who worked on his staff and on the staff of the Division's contractors.

This volume, the Summary Technical Report of Division 12, was prepared under the direction of the Division Chief and authorized by him for publication. It presents the methods and results of the Division's technical activities. In addition, however, it is the record of a group of men who contributed loyally to the defense of their country. They were few in number. Without their efforts, the course of the war might have been far different. To them all goes our sincere gratitude.

Vannevar Bush, Director
Office of Scientific Research and Development

J. B. Conant, Chairman
National Defense Research Committee

FOREWORD

In World War II the free peoples of the Western democracies appear to have waged a more workmanlike total war than did the total States of our enemies.

Our over-all planning was better, our mobilization more effective. And, although German technical superiority, particularly in certain ordnance items, persisted to V-E day, it is probably true that our over-all accomplishment in the development of new weapons surpassed that of our enemies. Our loose-jointed democratic military organizations permitted the flow of new ideas, while the close-coupled, centralized, and aristocratic Military Services of Germany and Japan, intolerant of civilians and rigid with inter-Service jealousies, set up barriers to such a free flow.

However, if our civilian-military collaboration was better than that of our enemies, it still left much to be desired. I fervently hope that men of goodwill in the Armed Services and in the Nation will discover how to make it what it should be—a close-knit partnership.

For five years we in Division 12 collaborated with the Armed Services of the United States, Great Britain, and Canada, the larger industrials, our colleagues in the Office of Scientific Research and Development, and our opposite numbers in Canada, Great Britain, and India. It seems doubtful that the experience we gained while pulling in this team differs essentially from that of other divisions of the National Defense Research Committee. Yet we believe that those who are now planning the basis for more effective future collaboration are entitled to our evaluation of the record for whatever it may be worth as the testimony of one small group, perhaps the smallest, in NDRC.

From the lessons we learned—or relearned—in Division 12, we have drawn certain conclusions, of which we consider the following four the most important:

1. We believe that the greatest possible *decentralization* is vital to the successful functioning of a single research authority charged with coordinating the development of new weapons. We have seen what happened in Germany and Japan with pyramidal, authoritarian organizations in charge of new weapons. We have also seen how effectively OSRD functioned. I am satisfied this was due largely to the farsighted policy of Dr. Bush who carried decentralization to such an extent that we in Division 12, for example were always able to use our autonomy to discover channels in which to explore possibilities and push ideas. It seems to me to be healthy that those with ideas should have more than one market in which to sell them, and that the Services, on the other hand, should be free to compete for such ideas. This is not a plea for the anarchy of indiscriminate channel jumping or for secret Service rivalries, but rather a plea to preserve many channels within the framework of whatever Joint Command is finally adopted and to keep them open for navigation.

2. I believe that in this war we closed too many channels to navigation and thereby overdid "security," some of which was perhaps more fancied than real. It should be possible in the future to strike a nicer balance between measures designed to achieve true security and the speed-up that comes when colleagues can talk with each other. It was perhaps fortunate for our side that compartmentation was apparently carried to even greater extremes by our enemies.

3. Admiral Mahan, speaking of the "unduly long" interval between changes in weapons and the resulting changes in tactics, says, "This doubtless arises from the fact that an improvement of weapons is due to the energy of one or two men, while changes in tactics have to overcome the inertia of a conservative class; but it is a great evil." I feel strongly that the way to overcome this evil in the shortest time is to recognize that those who develop a new weapon have a responsibility for supervising its early appearances in combat, until its full tactical exploitation becomes thoroughly well understood by all ranks. I could cite many examples. Two from my own experience are the DUKW and the antiaircraft barrage south of London against the German V-1 robot. In each case the civilian expert, working in combat and with Staff authority, doubled or trebled the tactical effectiveness of the weapon. Army forces in the field were quick to recognize the value of this type of civilian collaboration.

4. To a great extent we were merely merchants of ideas, and, in the desperate hurly-burly of the crisis years, we forgot at first certain truisms about how to sell ideas. We relearned them the hard way. I recite them here, not as discoveries, but merely as a check list.

a. Present an idea only after it has been thought

through to a tactical application. Then present it in correct military language.

b. When presenting an idea to a tired man already crushed with responsibility, do so in a way that makes a minimum of demand on his mental effort or imagination. Present it visually, simply, and dramatically.

Avoid discouragement over the inertia which must inevitably exist in every large military organization. Its members have many things to do and cannot move in all directions at once, not even in yours.

d. Remember that it is unrealistic to expect somebody else to equal your enthusiasms about your idea.

Division 12 was small, my technical staff consisting of two, later three, men; yet we were designated a "catchall" division. This directive, coupled with the strong inclinations of my associates, led us to develop in many unexpected directions to meet unforeseen contingencies.

The rather varied activities which ensued were of two kinds. On the one hand, we were assigned specific projects. On the other, we were often asked for, and frequently we volunteered, suggestions in fields in which we could not ourselves operate to advantage. In these cases, we gave every possible impetus to the initial momentum of the project, but left it to other organizations, whether in NDRC or in the Services, to see the thing through. While it is not possible to assess such work throughout all of its ramifications, I think it is of some interest to list a few examples of a type of informal activity to which we devoted a good proportion of our total effort.

Among such examples, I recall that in 1940 and 1941 we made suggestions to Army Ordnance which resulted in the eventual testing of cast and welded tank frames and hulls and in a marked modification of the silhouette of American tanks. Related ideas, by themselves or with concurrent proposals from others, led eventually to the General Pershing tank. Other suggestions, such as a mechanism at the driver's seat for controllably altering the width of tank treads, remain to be tried out. At about this time, we joined the chorus calling for more mobile heavy artillery, for higher velocity antitank weapons, and for the development of a dual purpose antiaircraft-antitank mount. These suggestions involved projects which clearly could be handled to better advantage directly by Ordnance, and many of them were developed in time to be of use. One suggestion in late 1940 for an illumination defense against night bombing was later reported used by the Germans at Hamburg. Some interesting suggestions in 1941, in the field of infrared, were ultimately assigned to Division 16 of NDRC. In 1941 we sketched up and proposed landing craft of the LST(1) type to transport amphibious medium tanks and launch them at sea. The LST idea, rejected at the time, was later carried out on the insistence of others. We were able to give some assistance to the second of these two projects, and amphibious tanks were effectively used at Okinawa in 1945.

In December of 1941 we renewed an earl[illegible] gestion for very long-range guided missiles as a means to sink the Japanese Fleet with airborne torpedoes. The agitation surrounding this project, known as Setting Sun, played a part in the creation of that Joint New Weapons Subcommittee of the Joint Chiefs of Staff which reviewed guided missile programs in 1942. This ultimately resulted in the creation of Division 5.

In August of 1943, following meetings at the Quebec Conference, we were invited by CINCPAC to confer at Pearl Harbor on the problem of the amphibious assault. We proposed the powerful, elastic, and economical type of amphibious assault described in Chapter 4. Regrettably it was not adopted in time for Tarawa, but later we had the opportunity to display this type of assault in the Southwest Pacific, where it was adopted, eventually becoming standard operating procedure throughout the Pacific Theaters.

In the course of our more formal activities, we were assigned some 34 projects which comprised about 100 subprojects. This work resulted in war production totalling about $300,000,000, at a cost for development of about $3,000,000 (1.0 per cent) and for supervision of about $200,000 (0.07 per cent). When I recall the pace at which these projects were driven, I feel that these ratios reflect the effectiveness of the planning with which my staff guided those furious activities.

It will be for others to make an objective assessment of our contribution. In my opinion, those projects developed under the cognizance of Division 12 which have had the most significant effect on the strategy and tactics of warfare:

1. The DUKW.
2. The doctrine of the amphibious assault.
3. The training programs for amphibious warfare.
4. The amphibious tanks.
5. The Weasel
6. The improvement of aircraft landing wheel brakes.

7. The development of automatic thread gages.
8. The magnetic compass for tanks

While some of our projects involved a certain amount of original research, most of our design decisions, particularly as regards vehicles to cross soft terrain, were based on meager fundamental data which could not be amplified at the time. Although these vehicles were successful, we feel that basic research in this field would now lead to improved designs.

We were recently asked by General Stillwell to suggest improvements in amphibious vehicles. We have outlined a program (Chapter 10) in which the most productive single item is this: While the potentiality of existing designs could perhaps be increased by half by refinements in the design, a still greater gain could be achieved by proper use of existing equipment. For example, in my opinion, adequate training and indoctrination would have doubled the tactical use factor of the DUKW fleet.

My very great personal gratitude is due to Palmer Cosslett Putnam, who served as my executive officer from 1941 until August 1943; Roger S. Warner, Jr., who served as technical aide from 1942 and as executive officer from August 1943 to December 1944; S. Murray Jones, who served as technical aide; James A. Britton, who served as administrative aide; and J. R. Kansas, who served as fiscal aide; and to William F. Durand, who served as Chief of Section 12.1. In addition, I am deeply obligated to the contractors and members of their staffs who worked closely with us, and to those other divisions of NDRC who provided us generously with their advice, assistance, and even the services of their members and their facilities.

We are indebted to the Members, and especially to the Chairman, of the National Defense Research Committee for wise guidance and financial support for our projects. In particular we are indebted to Dr. Vannevar Bush, who encouraged and supported our ideas, showed us the way out of our difficulties, gave us the freedom to do our job in our own way, and who always stimulated us. It has been an immense satisfaction to have earned his confidence.

Hartley Rowe
Chief, Division 12

CONTENTS

Chapter 1

THE WORK OF DIVISION 12

1.1 ORGANIZATION OF THE DIVISION

On July 1, 1940, a few days after the National Defense Research Committee [NDRC] had been established by order of the President of the United States, the predecessor of Division 12 appeared under the title of Section C. This group was to conduct investigations in the broad fields of subsurface warfare, electricity, mechanics, and transportation. Later, after several reorganizations, Division 12 was created and assigned the broad field of transportation.[a]

Sometimes by request but often on its own initiative, the division occasionally moved in other areas. As indicated in the Foreword to this volume, these extradivisional activities brought Division 12 personnel into many varied fields not contemplated in their original assignment.

Much of the time of division personnel was devoted to these extradivisional activities, and, while it is clearly impossible to assess their importance, it is believed that these indirect contributions had a substantial significance.

Within its assigned area, the division was at first requested by the Armed Services to work principally on vehicle components. Later it was asked to develop whole vehicles, such as the amphibious jeep and the Weasel. It then became evident that one of the division's products, the DUKW, had fallen into an unfortunate position — approved by the High Command but unwanted, unused, or unappreciated by many Service units. The personnel of the division were therefore invited into war theaters to consult with the staffs of theater commanders on amphibious logistics and on the tactics of the amphibious assault.

The division had hoped that it could begin demobilizing in April 1943 in order to free its personnel for these consultations in the theaters. The assignment of other responsibilities, however, made it impossible for the division to terminate its operations until June 1945.

During the periods of most intense operations, the technical staff of the division consisted of three men, with an administrative aide, a fiscal aide, and four office assistants in the Boston headquarters. Field offices were maintained for a few months in New York and Washington. Because of the nature of the division and the projects it supervised, the technical staff was actually a field staff and members operated almost entirely in the field, either in this country or overseas, as their assignments required.

At a time when the division was contemplating Project Turtle (the NDRC Tank), a number of distinguished people were prevailed upon to accept membership in the division. The project was cancelled, however, and it never became necessary to call them into consultation.

1.2 SUMMARY OF OPERATIONS

1.2.1 Amphibious Jeep

In the first major technical program undertaken by Division 12, the jeep was converted into an amphibian. The conversion consisted of wrapping a watertight hull under the parent vehicle, adding a propeller and a rudder, and making other changes required for amphibious operation. After limited but successful field tests on pilot models, the new vehicle passed out of NDRC supervision and production. It suffered from inadequate testing, inspection, and supervision of production; failure to recognize the necessity for a continuing development program in closest liaison with the using Services; failure to recognize the necessity for special training; and inadequate preliminary consultations with the using Services.[1]

1.2.2 The DUKW

In the spring of 1942, without Service approval, work was begun on the development of a wheeled amphibian designed to discharge military stores at a high rate of speed direct from ship to dumps and to support amphibious assaults. The amphibian was soon named the DUKW. It was decided that it would be a conversion of the Army truck then in highest production, the General Motors 2½-ton, 6x6 truck.

In June 1942, the War Department initiated a pro

[a] See OSRD Appendices, Contractors, and Service Projects, at back of volume.

[1] See Chapter 2 in this volume.

duction order for 2,000 units, but there was apparently no general Service acceptance of the vehicle.[c]

Under ordinary circumstances, the major work of the Office of Scientific Research and Development [OSRD] and its subdivisions on this program would have been terminated at about this point. In the end, however, these engineering phases came to represent only a minor and preliminary part of the OSRD contribution to the over-all DUKW problem. Accordingly, full-scale demonstrations were staged, special driving procedures were perfected, pressure was maintained on continuing testing and modifications, and special logistical and tactical techniques and equipment were developed. These and similar activities, culminating in the use of the DUKW in the invasion of Sicily in the summer of 1943, apparently satisfied the High Command of the potential value of the DUKW, but the Armed Services did not feel it advisable to allow OSRD to withdraw from the project at this point.

To realize the expectations of the High Command, it was found necessary that OSRD, in a second departure from a strictly engineering assignment, accept requests to stage demonstrations in nearly every combat theater, initiate and supervise training and retraining programs, exert all possible pressure to expedite modifications found essential in the field (and to make field improvisations in many cases), establish maintenance and operational procedures, assist in indoctrinating staff officers of many theater commanders, and, finally, urge at theater staff level the full exploitation of the DUKW not only as a logistical but also as a tactical weapon of war.

In descending order of importance, the principal shortcomings of the DUKW were its small size, the difficulty of unloading it, its poor performance in mud, and its low speed in water. To overcome these handicaps to both logistical and tactical performance, it is recommended that the DUKW be supplemented but not replaced by a 5-ton, ¾-track amphibian. The larger amphibian should be developed in two models, one for combat and one for support.[d]

1.2.3 The Weasel

The Weasel, a light, track-laying cargo carrier, was developed as a snow vehicle for a winter invasion of Norway. Later, it was modified for use in mud, sand, swamps, rice paddies, and similar difficult terrain. The first model, the T-15 or M-28, went into only limited production. The second model, the T-24 or M-29, went into full production and was used in both the European and Pacific Theaters where snow, mud, swamps, or marshes immobilized other vehicles. Although these first two models could float, they were not true amphibians, since they had no propulsive power in water. The third model, the M-29C, was developed and put into production as a true amphibian, capable of operation not only in difficult land terrain, but also in deep water. The M-29C is equipped with special cells to provide added buoyancy, and with rudders, skirts, and other shrouding devices to permit water propulsion by means of its own tracks.[e]

1.2.4 Amphibious Gun Motor Carriage

Two other amphibian conversions were nearing completion at the end of World War II. One is an *amphibious gun motor carriage* based on the standard M-18 gun carriage as designed and developed for use in land operations. It is self-propelled, using its own tracks for water propulsion, and can fire either ashore or afloat. A pilot model was undergoing final field tests at the end of the war.[f]

1.2.5 Paddy Vehicle

The second is a *paddy vehicle*, a light, amphibious cargo carrier designed for use in rice paddies and similar water-covered areas. Based on the T-39 light tractor, a pilot model of this vehicle was constructed and was also undergoing final field tests at the end of the war.[g]

1.2.6 Proposed Amphibious Vehicles

Several proposed amphibious vehicles were studied, but only one of these devices was carried as far as construction of a full-size pilot model. In a search for a large, amphibious cargo carrier, to be known as the *Pelican*, a survey was made of existing land vehicles and components available for use in large wheeled and half-track amphibians with rated payloads of 6 tons or more. Designs were developed for a still larger

[c] See Chapter 3 in this volume.
[d] See Chapter 4 in this volume.
[e] See Chapter 5 in this volume.
[f] See Chapter 6 in this volume.
[g] See Chapter 7 in this volume.

vehicle and plans were completed and model tests undertaken on a *15-ton, ¾-track amphibian.* Several *amphibious trailers* were designed for use with the DUKW and one experimental unit was constructed. Tests indicated that this unit was not satisfactory for practical use.[h]

1.2.7 Amphibious Devices

Several types of *flotation devices* were designed and studied for converting tanks and other land vehicles into amphibians. Two of these devices were actually constructed—one in which pontons were placed fore and aft of a light tank and a skirt placed around the tracks, another in which pontons were placed fore and aft on both sides of a medium tank. The latter device was used on a small scale in the last amphibious assault in the Pacific. An improved *amphibious trailer hitch* and a special *amphibious bow attachment* were both completed and submitted to final field tests just before the end of the war.[i]

1.2.8 Amphibious Studies

Several fundamental studies and a general theoretical consideration of design factors were other contributions in this field of amphibious research. One of these studies concerned *track propulsion in the LVT cargo carrier* and consisted of experimental towing tank tests conducted on two different models of the LVT cargo carrier, one with tracks completely submerged and the other with the return tracks out of water. The test data showed that, under the conditions of the investigation and with the track used, the emerged track is superior. A more complete study was then conducted on the problem of *submerged track propulsion.* Although it was found that in no case can the efficiency of the track propulsion equal that of screw propeller propulsion, proper design can greatly increase the efficiency of the former. Preliminary designs were made and theoretical studies were conducted on an amphibious structure to be used in an *assault across mud.* A survey of the fundamentals of *amphibious design* indicated the relative merits of the two types of design—the "ground-up" method, in which a completely new vehicle is conceived, and the "conversion" method, in which a mature, successful land vehicle is modified for use both on land and in water.[j]

1.2.9 Bridges, Pontons, and Ferries

An extended investigation of *ponton bridge reactions* for structures typical of those used in military operations resulted in the development of simple methods for the analysis of both continuous, unarticulated bridges and articulated bridges. A basic analysis was made of both types.[k] A variety of *bridge, ponton, and ferry* designs was prepared for military use. Among them are a 20-ton articulated bridge, a portable ponton bridge and ferry for 30-ton tanks, a structure designed for use as a ponton bridge or as a trestle or overpass for 60-ton tanks, a bridge constructed largely of steel pipe, a 200-foot portable bridge to carry a 30-ton tank, temporary highway trestles, a ponton ferry to support a 90-ton tank, tank-ferrying barges, an amphibious paddle wheel towboat, a tank-transport vessel, several types of ramps, a landing pier, and several types of quays.[l] Standard laboratory *tests of bridge components* were performed on several types of wood, aluminum, and steel balk fasteners, and bolts used, or contemplated for use, in military bridges.[m]

1.2.10 Torpedo Protection for Merchant Vessels

To provide improved safeguards against submarine attack, two types of wire nets were developed as *torpedo protection for merchant vessels* and were designed to be carried by vessels under way. One was found able to catch 30- to 35-knot torpedoes by their tails. The other, which can either be carried by the ships or be placed around them while moored, is able to stop 45- to 50-knot torpedoes by their heads. Both types were designed to give maximum efficiency, maximum useful life, and minimum drag through the water. Electrically energized cables were developed for use with these nets as a protection against magnetic torpedoes. The improved nets were not placed in production although various laboratory and field tests indicate their superiority.[n]

[h] See Chapter 8 in this volume.
[i] See Chapter 9 in this volume.
[j] See Chapter 10 in this volume.
[k] See Chapter 11 in this volume.
[l] See Chapter 12 in this volume.
[m] See Chapter 13 in this volume.
[n] See Chapter 14 in this volume.

1.2.11 Land Combat Vehicles

Plans were made for the development of a new series of land combat vehicles designed to combine the best features of tanks already tested in battle with the best new features which could be developed. The new *Turtle* series included lightly armored but highly mobile units suitable for air transport, medium units, and heavy units. Mock-ups were prepared of representative types of the first two groups in the series. More detailed study was conducted on the light, highly mobile combat vehicle, which was developed to include all-wheel drive, a hydraulic anti-recoil system, and a new type of independent all-wheel suspension enabling the vehicle to jump over ditches, fences, and similar obstacles. No complete full-scale vehicles were constructed.[a]

1.2.12 Land Vehicle Components

As part of the general study on tanks but also as a development leading to an attempted improvement of existing vehicles, other investigations were conducted on *tank components*. A centrifugal, self-cleaning air cleaner was devised for use in desert warfare but was found to be no better than available types. Mock ups were made of various types of vision devices for tanks, protectoscopes, gun shields, and other tank accessories. None of these devices was approved for production. In conjunction with another division of NDRC, *a mobile rocket launcher* was developed and placed in production for use on the DUKW.[a]

1.2.13 Land Vehicle Studies

In an effort to achieve *reduction of tank noise*, recommendations were prepared which indicated that the noise of the M 3 light tank could be reduced to approximately one-third its usual level. Tests indicated that this could be accomplished in part by acoustical treatment of the crew compartment, the engine compartment, and the air intakes and outlets, and by the use of the most quiet types of tracks but largely by the application of an adequate muffler and the installation of suitable rings or blocks to absorb the shock of the impact of the track blocks on the sprocket teeth. No practical use was made of these findings. A brief study of the *reduction of bouncing in towed gun carriages* led to proposed changes in the gun carriage suspensions and tow connections, but these were not accepted for use.[b]

1.2.14 Special Devices

Numerous devices and materials were likewise investigated by the division as part of its catchall assignment. These included primarily a study of *aircraft landing wheel brakes* and the development of improved designs achieving a threefold increase in capacity of energy absorption. These new designs made it possible for manufacturers to meet the specifications for such heavy bombers as the B-17, the B-24, and the B-29. Two new designs were prepared as suggested improvements on the Mark 51, Mod. 7 Navy *bomb rack*. Though both appeared to offer some advantages in preliminary trials, neither was accepted for production. A new type of *automatic thread gage* was developed and put in production; in service tests these gages gave up to a 10-fold increase in speed and a 300 fold increase in life, making it possible to speed thread gaging in industry and to eliminate a serious bottleneck in the production of needed war materials. Of the thousands of *pneumatic tire substitutes* proposed for civilian and military service, the twelve most promising were constructed and tested; although none of these had been found satisfactory when the project was terminated, one of them had been run for more than 10,000 miles over paved and unpaved roads at speeds up to 85 mph and appeared to deserve additional study. A *pneumatic life raft* designed to be carried by aircraft was developed and tested; it is believed to represent a decided improvement over existing models by providing maximum comfort for the crew, protection against sun and rain, camouflage protection against air attack, and small bulk in stowage, and in its ability to be sailed by inexperienced personnel. Plans were also made for an *airborne lifeboat* but no model was built. *Antifogging compounds* incorporating wetting agents as the active ingredients were developed and found effective in temporarily improving the quality of vision through windshields and other transparent surfaces. The use of desiccating devices, however, was recommended to prevent the fogging of some optical instruments. A group of new *rain repellent coatings* was developed to improve visibility through rain-covered windshields, and al-

[a] See Chapter 15 in this volume.
[b] See Chapter 16 in this volume.
[c] See Chapter 17 in this volume.

though none of these films provides prolonged protection, some are effective for periods up to 300 minutes in conditions simulating moderate to heavy rainfall. A *sine-disk propeller* designed for use in shallow water even when fouled with heavy marine growths was found in tests to give only low speed and to suffer from considerable cavitation and vibration. An immersion heater operated from the storage battery to heat the oil in the reservoir and other modification devices were developed to facilitate the *cold weather starting* of tank engines after they had been exposed to temperatures as low as −40 C.[f]

1.2.15 Special Studies

Ship turning research was conducted on numerous models and the results correlated with tactical data on full-size naval vessels in an attempt to determine and evaluate the effect of hull design and of hull appendages on the maneuverability of destroyers and other ships. Recommendations were prepared for general design features which would improve ship turning. This work, together with *cavitation research* studies, was turned over to the Navy for continuation.

In an attempt to correlate the performance of such vehicles as the Weasel on *snow* characterized by different properties, it was found that vehicle performance is affected by the density and depth of the snow, the penetration into the snow at different ground pressures, the water content of the snow, and particularly the shearing strength of the snow at different ground pressures. Correlation of these factors with meteorological conditions has shown that it is possible to make satisfactory forecasts of vehicle performance on snow not merely for a period of 12 to 24 hours, but even for many days ahead. An attempt to reduce the *visibility of wakes* of small amphibious vehicles used in land operations led to tests on chemical mixtures and mechanical baffles proposed as wake suppressors. Under the conditions of the tests, none of the mixtures or devices was found to possess any practical value. In a program of *wind and wave studies*, measurements of wave height, wind velocity, wave speed, wave length, and the velocity of propagation of waves, followed by the correlation of these measurements, made it possible to predict wave heights from wind velocities with reasonable accuracy.[g]

1.2.16 Special Projects

In order to conduct attacks on Japanese fleet units and dams, plans were made for a *10-ton, controllable missile* to be delivered by means of B-17's which would either be operated by a skeleton crew or be equipped with television and operated by remote control from a B-29 flying beyond range of enemy fire. Other special projects undertaken by the division or its antecedents include the *magnetic compass* for tanks, the *odograph*, *land mine detectors*, an *ultrasilent motor generator*, *map reproduction devices*, *defense methods against night bombing*, and plans for long-range, *glider-borne aerial torpedoes* to be towed and radio-controlled by heavy bombers. Personnel of the division likewise cooperated in the development of devices and methods for navigation in landing operations and for the destruction of land obstacles, and in the Manhattan Project.[f]

[f] See Chapter 18 in this volume.

[g] See Chapter 19 in this volume.

[f] See Chapter 20 in this volume.

Chapter 2

AMPHIBIOUS JEEP

(¼-Ton, 4x4 Amphibian Truck)

Summary

During the autumn of 1941 the ¼-ton, 4x4 general purpose truck was converted into an amphibian for use in carrying personnel. The chassis, power plant, transmission, differential, and wheel components of the parent vehicle were used in a hull with a propeller mounted in a tunnel, the necessary power take-off, a marine rudder interlocked with the wheel steering system, a bilge pump, a capstan, and other marine appurtenances. After limited field tests on pilot models, the new vehicle went into production with an original order of 6,000. Because of insufficient early testing of production models, inadequate inspection and supervision of production, failure to provide for a continuing development program, failure to recognize the necessity for training, and, particularly, failure to consult the using Services before production began, the amphibious jeep[a] was later discarded as a technical and tactical failure.

2.1 THE PROBLEM

The conversion of the well-tested and accepted ¼-ton, 4x4 general purpose truck into an amphibian—the first major project undertaken by Division 12—was first suggested in the summer of 1940 by the Quartermaster Corps, which initiated a formal request in the spring of 1941. This request included general specifications calling for a vehicle which, while retaining the land maneuverability of the jeep, would also be able to travel in calm or protected water at about 5 mph.

2.2 PROCEDURE

After a preliminary survey, it was recommended that the problem be solved by a full, permanent conversion of the standard ¼-ton, 4x4 vehicle.[b] Other proposals, including the use of detachable pontons and glider wings, were rejected. A program of towing tests was conducted on scale models,[c] and then, at the suggestion of the War Department, a contract was placed with the Marmon-Herrington Company[d] and later a development contract was made with the Ford Motor Company.[e] Both companies were authorized to produce pilot models according to the specifications already established on the basis of scale-model studies, and each followed relatively independent courses of development.

A lightweight, welded hull was prepared to include the necessary tunnels for axles, drive shafts, and propeller, and necessary seals were incorporated. In the Ford models, the hull structure was so designed that the normal chassis frame of the nonamphibious jeep could be retained. The other major additions included a power-driven bilge pump with an output of approximately 50 gallons per minute, a power-driven capstan in the forward deck, the necessary drive for the propeller, and a marine rudder operated from the regular steering column. Shielded air intakes were installed to supply air to the engine during operations in rough water.

In the Marmon-Herrington models, the power plant, transmission, differential, and wheel components remained the same as those on the parent vehicle, while the body was a waterproofed hull of welded steel construction with a propeller mounted in a tunnel at the stern and driven from the transmission through a power take-off. Other additions included a marine rudder interlocked with the wheel-steering system, a hand bilge pump, a hand capstan with 3,500 pounds direct pull, and shielded circulation for the conventional cooling system.

Both the Ford and Marmon-Herrington pilot models were completed and submitted for tests between February and April 1942.

[a] Project OD-95, formerly QMC-4.

[b] This investigation was conducted by Sparkman & Stephens, Inc., New York, N. Y., under OSRD contract OEMsr-151.

[c] These tests were performed at the Stevens Institute, Hoboken, N. J.

[d] This investigation was undertaken by the Marmon-Herrington Company, Inc., Indianapolis, Ind., under OSRD contract OEMsr-182.

[e] This investigation was undertaken by the Ford Motor Company, Dearborn, Mich., under OSRD contract OEMsr-187.

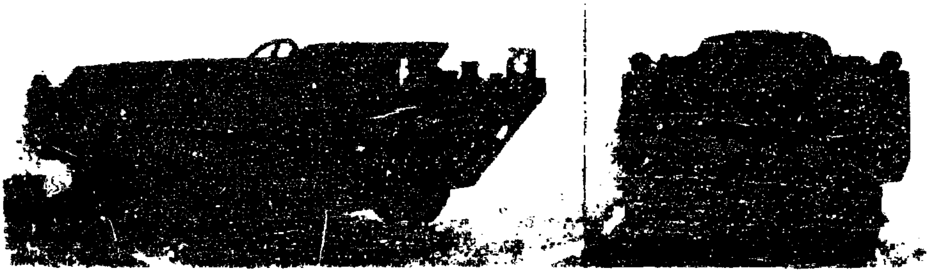


FIGURE 1. (A) Side view of Marmon-Herrington amphibious jeep. (B) Rear view of Marmon-Herrington amphibious jeep, showing the tunnel flap (to aid in going astern in water) raised to show tunnel.

2.3 RESULTS

The Marmon-Herrington pilot model[1] (Figure 1) has an over-all length of 179¼ inches, a width of 64 inches, a height of 67¾ inches, a ground clearance of 13 inches, a weight light of about 3,500 pounds, and a weight loaded of 4,300 pounds. Maximum speed is 65 mph on land and 5.5 mph in water. Grade ability is 60 per cent. After limited tests, this model was rejected by the Army.

The Ford pilot models[2] (Figures 2, 3, and 4) have an over-all length of 179½ inches, a width of 64 inches, a height of 41¼ inches, a ground clearance of 9¼ inches, a weight light of about 3,150 pounds, and a weight loaded of 3,950 pounds. Maximum speed is 65 mph on land and about 6 mph in water. Grade ability is 60 per cent. Field tests showed that these models could climb out of fairly steep and partly iced river banks, cross ploughed fields, knock down trees

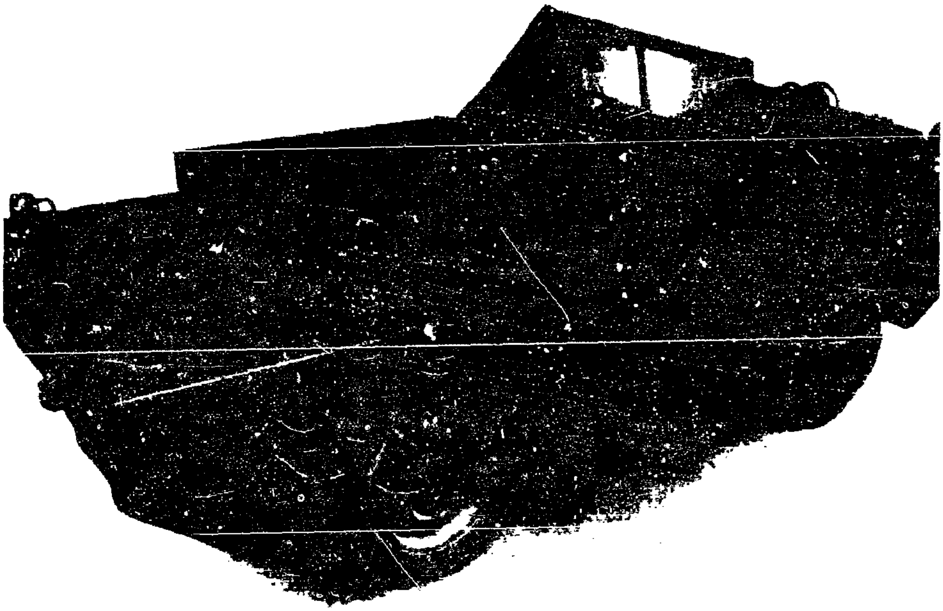


FIGURE 2. Side view of production model Ford amphibious jeep.

FIGURE 3. In water, final pilot model of Ford amphibious jeep achieves speed of about 6 mph.

up to 4 inches in diameter, and operate in moderate surf (Figure 5). After viewing demonstrations and motion pictures of these tests, the Commanding General, Army Service Forces, placed a production order for 6,000 units. (Later, this was increased to 12,774 units.) At this point, Division 12, having carried out its instructions, felt that the future of the vehicle lay between the manufacturer and the Army, and consequently turned its attention to other problems.

It soon became apparent that the amphibious jeep was not welcomed by the Army Ground Forces, who contended, first, that the vehicle was not seaworthy, second, that they had not been consulted during its development, and, third, that it filled no military need. It was not required as a scout car nor as a tactical vehicle, and it was too small to possess value as a logistical vehicle.

Many of the first thousand amphibious jeeps delivered to the Army sank after a few hours or days of operation which did not endear the vehicle to previously lukewarm military customers.

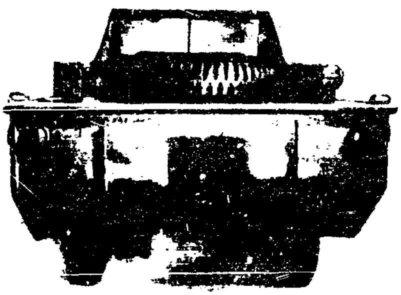


FIGURE 4. Rear view of production model Ford amphibious jeep.

It has become apparent that underlying the failure of this vehicle were a number of causes for which the responsibility must be shared by Division 12, the Army, the designers, and the manufacturers.

In the first place, Division 12 personnel, by the deceptive ease with which they handled the vehicle in surf, contributed materially to an over-optimism soon displayed by high-ranking officials of the Army Service Forces. However, the failure of the vehicle was not primarily due to its inability to negotiate surf.

When the design was frozen for production, the manufacturer transferred his design engineer to a glider project. There was a discontinuity between design and production. The new workers recruited for the assembly line were placed under supervisors new to the project. During the critical early period of production, there was no liaison between the design engineer and this new group or their supervisors, who were not familiar with the amphibious purposes of the vehicle nor with the significance of many assembly details. Division 12 had not yet learned the necessity for keeping in touch with the production of a new weapon and transferred its project engineer to the DUKW project. As a result of this failure, faults which became immediately apparent in early field use remained uncorrected, and vehicles continued to sink because of poor welding, erratic clearances, and a number of assembly practices which might have been satisfactory for a land vehicle but which, in the case of an amphibian, became sufficiently serious in the aggregate to result in grounding the vehicle in most commands.

Division 12 failed to insist, in the face of reputed manufacturing difficulties, upon the functional specification that the ignition system be waterproofed, as

was later carried out on the DUKW. When the feasibility of this was determined in the case of the DUKW, a suitable system of waterproofing the jeep ignition was immediately developed and later approved by the Office of Chief of Ordnance, Detroit. Because of long delays in placing it in production, all but 120 vehicles were delivered without it.

Division 12 had not yet learned the necessity for a logical and continuing development program. In the absence of such a program, design errors such as too small tires and excessive weight all remained uncorrected, even after their serious effects became apparent. At the time the final pilot model was accepted, it appeared that the weight light could be reduced from 3,150 pounds to perhaps 3,000 or less, but instead more equipment was added so that the final weight reached nearly 3,500 pounds. Introduction of a 12-volt electrical system at the insistence of the Signal Corps indicated that little or no consideration had been given to the effect of this on weight nor to the even more serious problems of overloading the fan belt and interfering with engine cooling. Insufficient thought was given to balanced cooling during operation in rough water with the forward intake closed. Throughout the development it had been assumed that this hatch would be closed for only a few minutes, but in actual operations it was found that occasionally this hatch would have to remain closed for much longer periods.

The early production models were not adequately field tested. Surf testing was not continued on production vehicles. Pilot model testing had been conducted without consideration of performance in mud or soft sand, and the only sand tests were those carried out on a relatively hard and flat area at Virginia Beach which did not reveal the difficulties which the amphibious jeep would face on less suitable sand. As a result, the need for larger tires and the desirability of providing means to change the tire pressure while under way were overlooked by Division 12. In cold-weather tests of the pilot models, the vehicles were always kept in a heated storage room and consequently were not seriously affected by ice forming in the hull and in the pump system, a situation which became quite serious in actual field operation.

A further major factor in the failure of this vehicle was the failure of the Army to institute a training program. Later, after some 2,000 vehicles had been produced, Division 12 and the manufacturer attempted jointly to introduce such a program to salvage the vehicle, but this proposal was turned down by the Army on the grounds that it would merely waste man-hours on a vehicle for which no essential role actually existed. The lack of a training program resulted in the failure of the drivers to get an adequate understanding of the operation and the limitations of the vehicle. Adequate publications and other training matter needed for vehicle operators and maintenance men did not reach the field until many months after the vehicles had been delivered and had failed.

Reports of these failures and the underlying causes for them reached Division 12 only by chance, and immediately every possible step was taken, in collaboration with the manufacturer and the designer, to improve the vehicles in the process of production, and to prepare modification kits and get them to motor pools and embarkation centers for the improvement of vehicles already delivered. Despite these efforts, it was impossible to catch even a substantial number of the vehicles before they reached their eventual users. The 12,354th amphibious jeep to come off the production line still did not have a waterproofed engine. After 12,774 units had been produced, the line was shut down.

Division 12 and other divisions of the National Defense Research Committee, together with many of the military agencies involved, derived a considerable education from this unfortunate experience. In the case of Division 12, these lessons were applied most profitably in the development of the DUKW, which was closely followed by division personnel from conception of the vehicle through production to its tactical use by virtually every DUKW company, until after the end of the war.

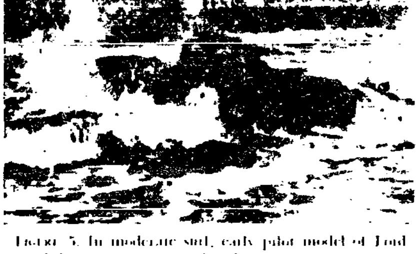


FIGURE 5. In moderate surf, early pilot model of Ford amphibious jeep impressed military observers. Production models were not waterproofed and the engines drowned out.

The DUKW, the "truck that goes to sea," developed as an amphibian for operation on land and water and for the zone between — surf and near beach sand.

Chapter 3

THE DUKW: ITS DEVELOPMENT

Summary

In the spring of 1942, without Service approval, work was begun on the development of a wheeled amphibian designed to discharge military stores at a high rate of speed directly from ship to dump and to support amphibious assaults. The amphibian was soon named the DUKW.

It was decided that it would be a conversion of the Army truck then in highest production, the General Motors 2½-ton, 6x6 truck. Pilot models were built with all main truck chassis units retained in their conventional location and with a watertight hull wrapped under the frame. A rudder, a propeller, bilge pumps, and other marine appurtenances were added. Later a controllable, central tire-inflation system was perfected and incorporated to adapt the DUKW for operation over a wide variety of beach conditions.

In early tests, the DUKW showed a speed of about 6.5 mph in water and 45 mph on land and readily negotiated the moderate surf available. Later tests showed it could go through quite heavy surf.

In June 1942, the War Department initiated a production order for 2,000 units, but there was apparently no general Service acceptance of the vehicle.

Under ordinary circumstances, the major work of the Office of Scientific Research and Development [OSRD] on this program would have been terminated at about this point. In the end, however, these engineering phases came to represent a minor and preliminary part of the OSRD contribution to the over-all DUKW problem. Accordingly, full-scale demonstrations were staged in rough weather to illustrate the strategic and tactical worth of the new weapon. Special driving procedures were perfected for operation not merely across soft sand but also across coral. Pressure was maintained on continuing testing and modifications. Special logistical techniques and equipment were developed to enable the DUKW to discharge loaded vessels, to dump cargo quickly on land, and to ferry tanks, trucks, and airplanes. Special tactical techniques and equipment were developed for carrying and firing the 105-mm howitzer, the 25-pounder, the 3-inch antitank rifle, and the 4.5-inch beach barrage rocket.

These and similar activities, culminating in the use of the DUKW in the invasion of Sicily in the summer of 1943, apparently satisfied the High Command of the potential value of the DUKW, but the Armed Services did not feel it advisable to allow OSRD to withdraw from the project at this point.

To realize the expectations of the High Command, it was found necessary that OSRD, in a second departure from a strictly engineering assignment, accept requests to stage demonstrations in nearly every combat theater, initiate and supervise training and retraining programs, exert all possible pressure to expedite modifications found essential in the field (and make field improvisations in many cases), establish maintenance and operational procedures, assist in indoctrinating staff officers of many theater commanders, and finally urge at theater-staff level the full exploitation of the DUKW not only as a logistical but also as a tactical weapon of war.

At the end of the war, about 13,000 United States Army and Marine Corps troops had been organized into about 76 activated DUKW companies of 50 DUKWs each. About 75 per cent of these men had been trained or retrained under OSRD supervision either in this country or overseas. About 5,500 British troops had been organized into 12 DUKW companies of 120 DUKWs each, and, similarly, most of these forces had received OSRD indoctrination in England, Scotland, or India. Additional small consignments of DUKWs were issued to units of the U. S. Coast Guard, Signal Corps, and other groups, some of which received OSRD training.

A total of 21,147 DUKWs had been produced by August 15, 1945, and more than 6,000 additional units were on order.

In descending order of importance, the principal shortcomings of the DUKW were its small size, the difficulty of unloading it, its poor performance in mud, and its low speed in water. To overcome these handicaps to both logistical and tactical performance, it is recommended that the DUKW be supplemented but not replaced by a 15-ton, 8×8 truck amphibian. The larger amphibian should be developed in two models, one for a combat role and one for the support of the assault and for purely supply functions.

2.1 INTRODUCTION[a]

In the spring of 1942, some of the existing shipping difficulties and the nature of some of the probable offensive actions to come had been under study by OSRD personnel[b] for some time.

It was known that Lend Lease ships in ports such as Basra sometimes waited several months to be discharged into sailing lighters. In ports such as Bristol, the facilities were modern but insufficient to cope with war tonnage, and ships waited their turn. It seemed clear that if such ships, while lying in the stream, could be at least partially discharged directly to railroad sidings or dumps at a high rate of speed, their turn-around would be speeded and the effective tonnage of the Allied merchant fleet increased proportionately.

Further, it seemed clear that the invasion of Europe, at whatever point, and the reconquest of islands in the Pacific would both require new techniques in landing operations and new amphibious equipment, including vehicles, to make these operations possible.[c] Except in rare instances, it was expected that there would be no harbors or piers ready for use by the invasion forces, certainly not after Allied bombings and sabotage and enemy demolition. There would be few beaches where cargo could be passed directly from ship to truck. Instead, it was expected that landings would be made on open beaches, over reefs and sand bars, and that military cargo and possibly combat vehicles must often be carried from a ship first over deep water, then perhaps over sand or coral and more deep water, and finally either up to a transfer point or else directly to the combat units waiting for the supplies.

No vehicles then in production or under development could adequately fill such multipurpose assignments. The Roebling Alligator, progenitor of the LVT series as redesigned for the U. S. Marine Corps by Food Machinery Corporation, Borg-Warner Corp., and others, appeared to approach this goal most closely, but this track-laying amphibian is primarily for combat use and excels in mud and swamps. Its use as an open-sea cargo carrier is limited by poor maneuverability at shipside, relatively poor performance in heavy surf, low land speed, relatively high maintenance, and excessive damage to roads continuously subjected to its grousers.

Early in April 1942, without formal request or approval from the War or the Navy Department, and indeed in the face of high-level opposition to what was labeled "just another special vehicle," the Director of OSRD authorized Division 12 to begin work on one such vehicle, soon baptized the DUKW. To save time in development and to simplify field maintenance, it was arbitrarily decided that it would not be a "ground-up" design but a conversion of the Army truck then in highest production, the General Motors CCKW-353 2½-ton, 6x6 truck.

The basic design having been roughed out, developmental engineering and experimental shop work were begun on April 24, 1942, at the Pontiac, Michigan, plant of the General Motors Corporation Truck and Coach Division, whose extensive design, research, test, and shop facilities were mobilized behind this project at the suggestion of Chief, Motor Transport Division, Office of Quartermaster General. Personnel of Sparkman & Stephens, Inc., were placed in charge of marine problems.[d]

Under ordinary circumstances, the major work of OSRD on this program would have been terminated with the completion of designs and the construction, testing, and modification of pilot models. This, however, became an unusual program, and in the end the engineering phases came to represent only a minor and preliminary part of the role which OSRD was asked to play in developing the over-all potentiality of the Allied DUKW fleet.

[a] For a discussion of the military use of the DUKW, modifications, training, and recommendations for future development, see Chapter 4 in this volume.

[b] The development of the DUKW and its later application in various theaters were carried out by four men working at different times under the auspices of different components of OSRD. Thus, the development of the amphibian was directed by Division 12 of the National Defense Research Committee [NDRC]. The amphibious warfare mission to theater commanders were carried out by former personnel of Division 12 and of one of its contractors serving as personal representatives of the Director of OSRD. Subsequent work along these lines in the Pacific Theaters was done under the administrative care of the Office of Field Services [OFS], and in the European Theater under the administrative care of OSRD, London Mission.

For simplicity work done under any of these arrangements will be referred to in Chapters 3 and 4 as work done by or for OSRD.

[c] See design for proposed tank carrier ship, to provide sea-lift for amphibious tanks (Chapter 12, Section 12.16), and proposed nestable ponton ferry (Chapter 22, Section 12.11).

[d] This investigation was conducted by Sparkman & Stephens, Inc., N. Y., under OSRD contract OEMsr-151, and by the General Motors Corporation, GMC Truck & Coach Division (formerly Yellow Truck & Coach Mfg. Co.), Pontiac, Mich., under OSRD contract OEMsr-870.

Once the development program was well under way, the next part of the problem was to obtain acceptance by the Armed Services.[*] This was not easy. The DUKW idea did not sell itself. This idea may be recapitulated and summarized as follows:

Logistical Uses of the DUKW

1. To discharge military stores at a high rate of speed directly from Liberty ships lying in the stream to rail sidings or dumps, in harbors without modern facilities, like Basra; or in harbors with congested facilities, like Bristol; or in harbors which had been put out of action by war, like Cherbourg.

2. To discharge combat stores at a high rate of speed directly from combat-loaded vessels (AKAs, LSTs, etc.) to dumps, possibly across beaches storm-lashed or girded by outlying reefs or bars.

3. To evacuate casualties directly from forward areas to hospital ships, delivering the wounded to the receiving station on the boat deck without the shock of the sometimes unavoidably rough handlings at the surf line and at shipside.

It was found that, with the high-speed DUKW mooring system by which the DUKW is automatically located precisely under the cargo boom, a suitably loaded ship could be discharged into DUKWs at a continuous rate in excess of 20 tons per hatch per hour. In 1942 and 1943, this implied a great reduction in ship turn-around time and meant that a fleet of a few thousand DUKWs could, in effect, have added several million tons to the Allied merchant fleet.

Tactical Uses of the DUKW

1. To transport 105-mm howitzers, ammunition, and combat troops directly from a ship to a forward battery position for fire in support of an amphibious assault.

2. To provide close-supporting barrage fire, with 4.5-inch beach barrage rockets, during the critical minutes just before and just after a landing.

3. To transport combat stores at a high rate of speed directly to forward positions from combat-loaded ships (AKAs, LSTs, etc.).

4. In general, to achieve strategic surprise by supporting an assault on such a coast and through such heavy surf that the enemy "knows we will not land there."

Advantages

These logistical and tactical doctrines imply several benefits:

1. A means is provided of getting mobile artillery ashore in close support of the assault and prior to the arrival of LSTs.

2. There would be freed for other duties a very considerable number of troops and special equipment otherwise tied up in beach parties, sometimes forming human chains in the surf to pass stores from landing boats to skid pallets and then to trucks.

3. Except in rare cases, the burden of the assault phase would not be increased by a requirement for bulldozers, Summerfeld matting, and other aids to beach crossing.

4. From the foregoing, it follows that a beachhead supplied by DUKWs could expand faster than one supplied by LCVPs, LCMs, or other landing boats of the same general size.

However self-evident they may appear in 1945, in 1942 these doctrines were simply the untried proposals of certain OSRD personnel and carried no conviction to policy-making officers in the War Department. Only the Chief, Armored Force, was interested in the DUKW. He was seeking a means to get tanks ashore over outlying reefs, and the DUKW offered a possible solution to his problem. A largely futile sales campaign was carried on throughout the summer of 1942 in the face of continuing opposition. While a small production order had been placed in June 1942 on the directive of the Commanding General, Army Service Forces [ASF], it was feared that, without general and warm Service acceptance, the DUKW would suffer the fate of the amphibious jeep—be issued to untrained troops and be condemned as a failure. This actually did happen to a small group of DUKWs at Milne Bay in June 1943.

Accordingly, OSRD deemed it essential to mount a full-scale and compelling demonstration of the DUKW. With the assistance and encouragement of certain officers, particularly Colonel R. R. Robins, Development Branch, ASF, and General Daniel Noce, Commanding General, Engineer Amphibian Command, such a demonstration was organized in October, mounted in November, and carried out at Provincetown, Massachusetts, early in December 1942. It achieved a limited objective, and 25 DUKWs

[*] The amphibious jeep had been put into production without consulting the customers, who, without indoctrination, were allotted so many per division—an important factor in the failure of this amphibian to win many friends.

were forthwith ordered to each of four theaters by the Assistant Chief of Staff, War Department General Staff [WDGS], G-3.

This limited acceptance, under these circumstances, of such a highly specialized vehicle as the DUKW resulted in a delay in the development of training programs and training aids, in the selection of training centers, and in the indoctrination of higher command. These all inevitably lagged behind production, then getting under way, as well as behind the needs of the theaters. This situation would have been less acute had the DUKW been recognized originally as a tactical weapon, but it was first accepted as a purely logistical vehicle and its destiny was accordingly placed in the hands of the Transportation Corps [TC]. This corps, functioning at a relatively low and noncombat echelon, was unable to command adequate facilities or personnel for the job of fully exploiting the strategic possibilities of the DUKW.

When it was learned that a consignment of DUKWs was being sent to North Africa, and that on arrival their trained crews and officers were virtually all transferred to other duties, it was feared that this meant disaster to the DUKW program, and OSRD requested permission to send training personnel to North Africa. This was refused. OSRD then requested the manufacturer to send personnel to North Africa to help with this training problem, but the manufacturer, not unreasonably, felt that he had no responsibility for the manner in which the Army used the DUKWs. Unwilling to let the weapon go by default, OSRD arranged with the Assistant Chief of Staff, WDGS, G-4 to send an emergency photographic training manual to North Africa, and decided to make itself available to work more intimately with the Armed Services in matters relating to the use of the DUKW. In response to War Department requests, and in cooperation with various officers, OSRD personnel therefore set out to attack the problems of selecting training centers, drawing up and conducting training courses, creating training aids, drafting Tables of Organization and Tables of Equipment, writing and editing training and maintenance manuals, attempting to arrange for a flow of spare parts, and, finally, assisting in the preparation of a sound film for the Joint New Weapons Committee of the Joint Chiefs of Staff, which outlined some of the strategic global possibilities of a large fleet of DUKWs.

In March 1943, the 451st Amphibian Truck Company [ATC] arrived in Noumea. It had been trained at Fort Story. It was in fine fettle. In a test it discharged a Liberty ship in Noumea Harbor directly to a dump at a rate of 22 tons per hatch per hour, compared with the average rate in Noumea at that time of about 7 tons per hatch per hour with lighters. The test was reported to the War Department.

This report broke the ice. It was followed in July, after the invasion of Sicily, by a message from the Supreme Allied Commander, Mediterranean Theater, to the Chief of Staff:

"Amphibious truck, two and one-half ton, commonly called DUKW, has been invaluable. It greatly facilitates flow of supply over beaches and on one beach was used as assault craft. Mechanism should be kept secret as long as possible. We would be delighted to get some more of them."

Production was stepped up and plans were drawn for the DUKW to bear a heavy share of the burden of supporting some of the forthcoming operations. OSRD redoubled the pressure to correct faults in the DUKW.

For a time OSRD believed this high-level acceptance meant that all necessary steps would be taken to institute more rigorous training and, especially, the indoctrination of field commanders. It was soon apparent, however, that while the DUKW fleet had looked good to General Eisenhower in comparison with the landing boat-human chain alternative, it had in fact delivered less than 25 per cent of its potential. In reality, the measures requisite to a realization of the High Command's expectations could not be taken by the Military, not many of whom had had experience in small boats and still fewer, in surfmanship.

At this point, it was realized that OSRD had no alternative but to accept invitations to see the DUKW through into combat.

Upon invitation, OSRD personnel consulted on amphibious problems with the staffs of the theater commanders, including Commander-in-Chief, Pacific Fleet [CINCPAC], Southwest Pacific [SOWESPAC], South Pacific [SOPAC], Southeast Asia Command [SEAC], Mediterranean Theater of Operations [MTO], and European Theater of Operations [ETO].

At the request of the Chief, Combined Operations (British), OSRD personnel were sent to Scotland in May 1943 to train British DUKW drivers, make good equipment deficiencies, and supervise loading for the

Sicilian invasion. Later, at the request of the Commander-in-Chief, SEAC, similar assistance was provided in India before the amphibious assault on the Burma coast. Similar requests resulted in the assistance of OSRD personnel in Wales in training DUKW drivers before the Normandy landings, and later in supervising a DUKW school at Waimanalo, Oahu.

A doctrine of amphibious assault was first proposed by OSRD at a series of conferences called by CINCPAC at Pearl Harbor in August 1943. Presented as being suitable for use at Tarawa, it was rejected by Amphibious Forces, Pacific Fleet. This doctrine, which was demonstrated later at Milne Bay, New Guinea, involved the coordinated use of LSTs, DUKWs, and LVTs, with the DUKWs carrying rockets and 105's during the assault phase. It was used at Arawe and later became largely standard operating procedure throughout the Pacific.

In SOWESPAC, OSRD personnel corrected abuses in DUKW fleet operation at Guadalcanal; determined by reconnaissance and map study the possibility of using DUKWs on Munda, Rendova, Kolombangara, Vella Lavella, Empress Augusta Bay, and the Treasuries; analyzed ship-to-shore logistics of the New Guinea ports of Milne Bay, Oro Bay, Buna Bay, and Lae; determined by reconnaissance the feasibility of using DUKWs at Finschhafen; evolved quantitative doctrines and established performance yardsticks for DUKW companies; and arranged and supervised numerous demonstrations.

Many conferences were held in theaters, including three highly productive ones at the request of Allied Forces Headquarters [AFHQ], Algiers, in December 1943, at which daily tonnage rates to be guaranteed to the planners of the invasion of Southern France were recommended and the prerequisite training, indoctrination, maintenance and spare parts procurement programs were outlined, together with the tactical doctrines developed in the Pacific.

The major problem of the optimum utilization of the Allied DUKW fleet was not solved at War's end, and OSRD was requested to maintain its stopgap role until after V-J Day, when an OSRD representative, having served on the Staff of the Commanding General, Army Ports, Okinawa, was sent to advise on the operation of the DUKW fleet in Korea.

SCOPE OF THIS SUMMARY REPORT

It is impossible in this Summary Technical Report to assess the original objectives of OSRD, the design decisions, the later recommendations for design modification at the factory and in the field, the various solutions to the problems of maintenance, or the conclusions and recommendations[a] without some reference to the logistical and tactical assignments actually given to the DUKW in theaters of operation and to the role of OSRD in shaping such amphibious doctrines. Accordingly, the chapters devoted to the DUKW are not wholly confined to a recital of engineering matters, but also touch briefly on such related portions of the over-all problem of the optimum use of the Allied DUKW fleet as may be necessary for a clear assessment of the technical work of OSRD. These related matters will be found described more fully in the historical records of OSRD.

3.2 THE DESIGN PROBLEM

As indicated above, the technical development of the DUKW was based on the arbitrary decision that this vehicle would not be a "ground-up" design, but a conversion of the General Motors Corporation CCKW-353 2½-ton, 6x6 truck.

The basic specifications called for a water speed of about 6 mph, minimum profile, minimum weight, and land performance equivalent to that of the parent land vehicle. The conventional location of all main chassis units would be retained and a watertight hull would be wrapped under the frame and below the engine, transmission, and transfer case, leaving the wheels, axles, springs, and drive shafts exposed.

3.3 DESIGN PROCEDURE

3.3.1 The Fundamental Decision

It was expected at the outset that developing a new amphibian by the conversion of a well proved land vehicle already in production would accelerate the whole program, making it possible to ut... many standard components and design features, while at the same time simplifying maintenance in the field, since maintenance techniques and many spare parts for the parent vehicle would already be available.

It was recognized that this decision sacrificed the possibility of the better water performance which might be expected from a "ground-up" design. The

evidence indicates that this was a fortunate decision: in a global war, spare parts procurement proved a constant nightmare.

3.3.2 Basis of the Design

The General Motors Corporation CCKW-353 2½-ton, 6x6 truck[f] (Figure 1) had been in production for a year and a half, it had been well received in the field, spare parts were already available at depots, and its design seemed well-suited to amphibious conversion. Its engine had been in production for 10 years, and some 500,000 were in use on buses and trucks.

In order to change this truck into the amphibious DUKW,[g] it was apparent that the CCKW power plant, transmission, transfer case, drive shafts, axles, brake system, and related accessories could be used without serious change, while the cab and body parts, fenders, hood, engine cooling system, winch drive, steering gear and controls, some frame members, and bumpers would have to be removed. The major new additions would include a hull, which would have to be designed specifically for the job, together with such accessories as a propeller, a rudder, bilge pumps, hull drain valves, air ducts, cargo compartment, cockpit, windshield, coamings, hatch covers, instruments, controls, a modified engine cooling system, and a modified winch drive.

The selection of the CCKW meant that 85 per cent of the amphibian would already be a mature, "debugged" mechanism. A great effort was made to "debug" the remaining 15 per cent of the conversion in a very short time.

[f] C for "1941," C for "conventional," K for "front-wheel drive," and W for "two rear driving axles" (GMC symbols).

[g] D for "1942," U for "utility," K for "front-wheel drive," and W for "two rear driving axles" (GMC symbols).

3.3.3 Scale Model Study

Scale model tests of many proposed hull designs were run intermittently throughout the period from April 1942 to July 1943.[h] These included resistance tests on experimental designs and on the first pilot models, a study of the effect of various changes proposed for the hull, and tests on the production design. In addition, self-propelled tests were conducted on a scale model of the production design in order to aid in determining the stability, propulsive coefficients, and turning characteristics of the final vehicle.

Figure 2 illustrates the design of the first of more than a dozen scale models which were studied, while Figure 3 indicates the design which was finally incorporated in the actual production amphibian.

Tests on the scale models indicated that the full-

[h] These tests were conducted by the Stevens Institute of Technology, Hoboken, N. J., under supervision of Sparkman & Stephens, Inc., New York, N. Y.

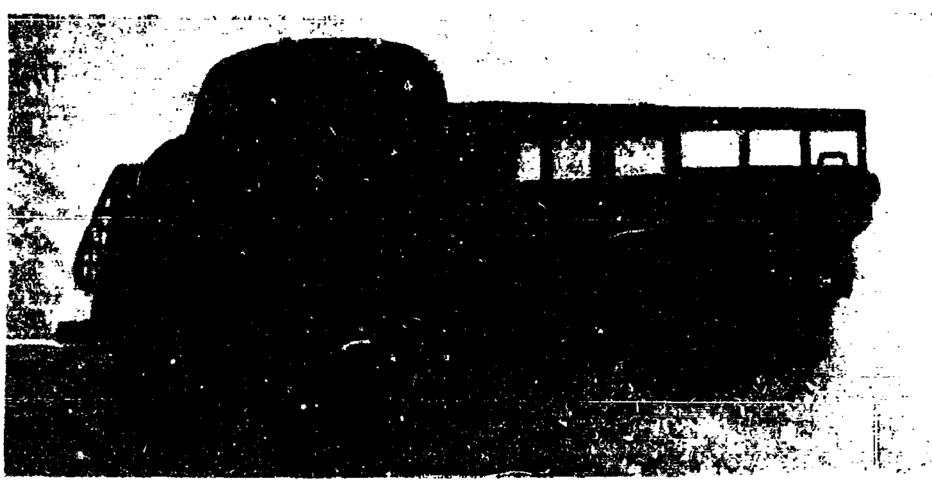


FIGURE 1. General Motors Corporation CCKW 2½-ton, 6x6 truck, parent vehicle of the DUKW.

size amphibian with a displacement of 20,390 pounds would give a speed of roughly 5.9 mph at a propeller speed of 950 rpm, 6.1 at 1,000, and 6.3 at 1,050. At 5.9 mph the resistance in effective horsepower would be 16, at 6.2 mph it would be 19.2, and at 6.5 mph it would be about 21.

Comparative results emphasized the beneficial effects of housing the wheels, differentials, and suspension in tunnels. A scow-type bow appeared desirable at the speeds tested for reducing resistance, increasing stability, and improving surf ability without interfering with land operations.

3.3.4 Development of the Design

HULL

The hull was originally designed on the basis of fundamental engineering theory and the results of the scale model tests. Many of the original features were arbitrarily selected. For example, maximum ground clearance was established by the standard location of the bottom of the transfer case. Consistent with the ground clearance selected, it was thought desirable to let the hull provide maximum screening for the wheels and axles. The shape of the bow and the stern was controlled largely by arbitrarily selected angles of approach and departure. The principal bow plate was made flat for simplicity of construction. The hull sides were rounded at the bow to provide more clearance in maneuvering, better visibility, and less water resistance. The extreme tip of the bow was somewhat snubbed to decrease over-all length and provide more rugged construction. In the stern, all possible displacement was retained to reduce the tendency of the stern to settle and thus to obviate the need for increased freeboard, which would make cargo handling more difficult. The maximum allowable beam of 96 inches was selected to give maximum displacement without excessive height for land operations. This was later expanded to 99 inches including rub rails.

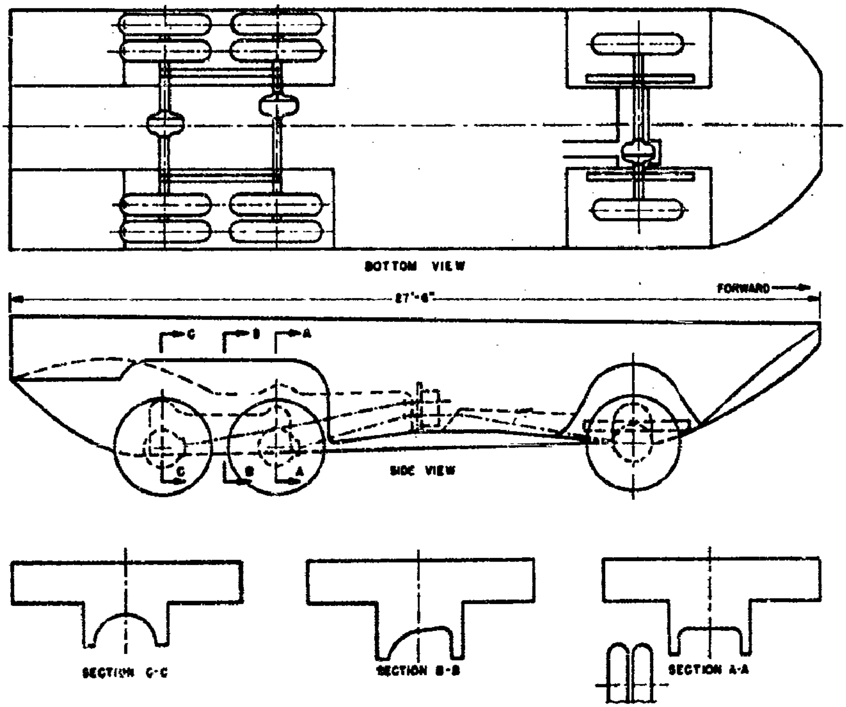


FIGURE 2. Design of first scale model of DUKW, showing sections of rear tunnel.

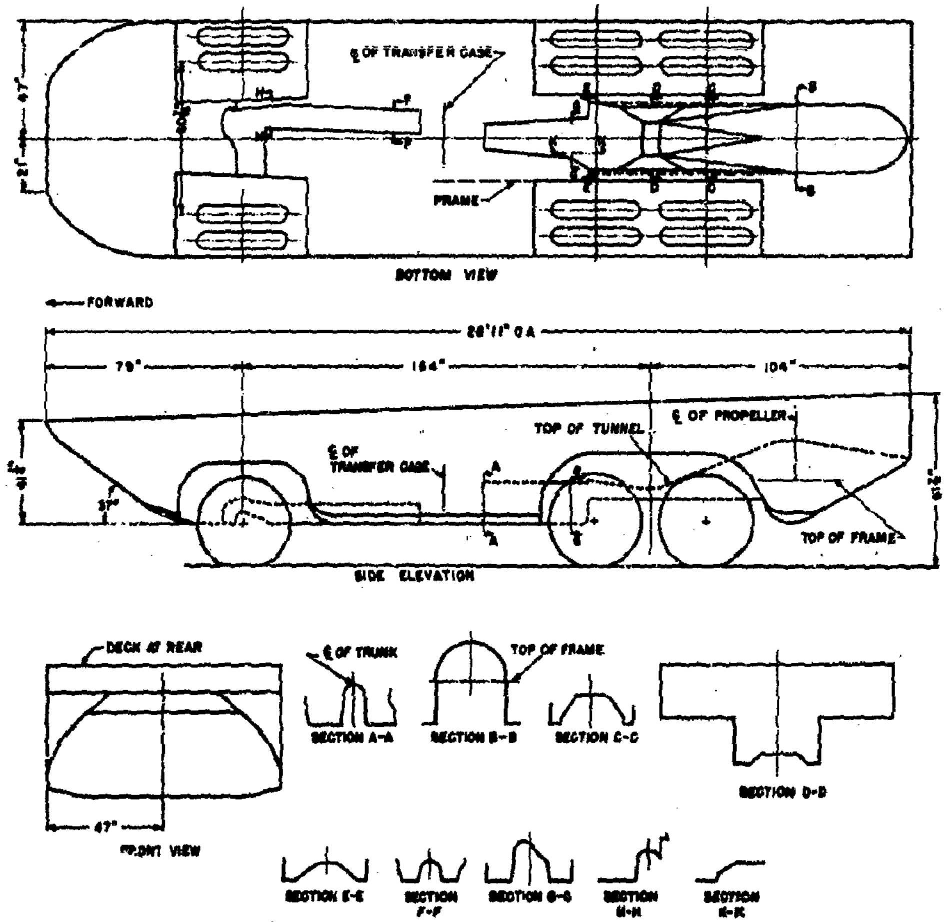


Figure 3. Design of final scale model of DUKW used for towing tests.

Figure 4. Cab-over-engine pilot model of DUKW, under way in water test.

FIGURE 5. Cab-over-engine pilot model of DUKW, first full-scale unit constructed.

Actual water tests showed the benefit of extending the length of the stern in order to furnish additional flotation where it was sorely needed and to relocate the propeller for higher speed. Cutting back the rear portion of the front wheel cutouts proved slightly advantageous, while more obvious improvement resulted from adding covers over the front cutouts, which significantly reduced the visible bow wave. Rear wheel house covers were added later to protect accessory tire-pressure control leads.

In the first pilot model, the cab was placed over the engine to give maximum visibility for the driver and maximum cargo space (Figures 4 and 5). In all other pilot and production models, however, the cab was placed behind the engine. This made it possible to lengthen the bow deck and cover the engine completely, providing increased protection against water and more accessibility to the engine. With the cargo space thus moved back, the load on the front axle was relieved. By increasing the width of the compartment, the necessary cargo space was maintained.

Another revision resulted from a decision to economize on steel by making the driver's compartment out of plywood.

Since the final hull design release in August 1942, the only important change in hull shape has been to raise the height of the cargo space coaming by 6 inches at the rear end. This provides the added freeboard to accommodate the increased loads which it was found practical to carry. In all hull construction, welded steel is used with liberal reinforcing (Figures 6 and 7).

The hull is constructed of welded sheet steel, with a maximum plate thickness of about 0.1046 inch at the bow, 0.0938 inch at the bottom, and 0.0625 inch at the sides. Its relatively thin skin is reinforced inside by transverse "hat section" channel frames and outside by similar longitudinal rub rails. The com-

FIGURE 6. Inside view of DUKW hull, showing construction of wheel cutouts and tunnels for drive shafts.

plete hull is very stiff and requires no structural reinforcement.

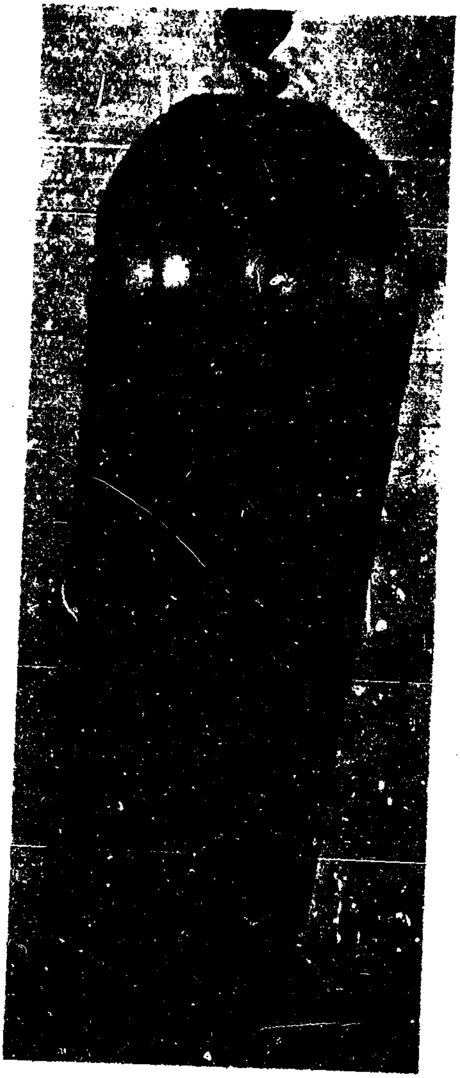


FIGURE 7. Bottom view of 1944 production model DUKW, showing wheel cutouts and housings for drive shafts, and propeller tunnel.

ENGINE

With the general specifications of the hull determined, the next problem was to obtain the most effective propulsive power. For efficiency in production and in field service, and because a larger engine would require a new power train, the standard GMC 270 engine already used in the CCKW truck was adapted for the DUKW. This six-cylinder engine was satisfactory for land performance but required some modifications for use in an amphibious vehicle.

In the first experimental model, with cab over engine, the limited space beneath the cab floor made it necessary to use updraft carburetion. In later pilot models and all production models, with the cab located behind the engine, standard downdraft carburetion was adopted. The muffler was altered to reduce the noise level, and the distributor, the coil, the spark plugs, the starter, and the generator were waterproofed.

The first pilot model had no provision for hand-cranking the engine at sea, thus leaving the vehicle completely helpless in case its mechanical starter failed. Production models were supplied with a specially designed lever and ratchet on the water propeller shaft (Figure 8).

FIGURE 8. Ratchet on water propeller shaft and special lever used for hand starting.

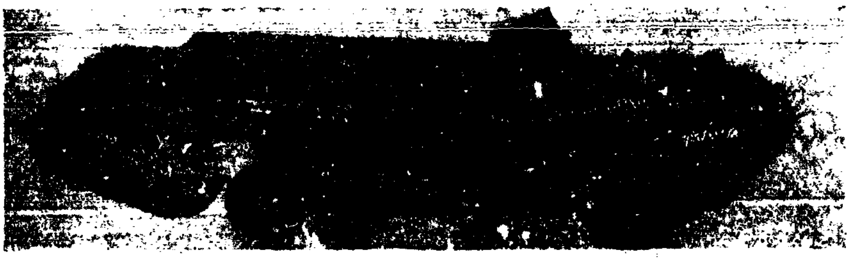


FIGURE 9. Power train of production DUKW.

The power plant as used in the 1944 production models is shown in Figure 9.

PROPELLER

Once the power which could be expected from the engine had been established, major attention was given to the design of the propeller, its position, and the design of the propeller tunnel in the hull.

Original estimates, which were supported by numerous tests, indicated that maximum efficiency would be given by a maximum propeller diameter and a pitch ratio of slightly more than 50 per cent. Although the maximum diameter was 26 inches, this was reduced to 25 inches to give needed additional ground clearance, and the pitch was set at 13½ inches. These dimensions were used for the first production units, but the pitch was later changed to 14 inches to give greater fuel economy.

It was first thought necessary to run the engine at approximately 3,000 rpm in order to use the maximum available power. In the course of the test program, however, it became apparent that virtually as good results could be obtained without exceeding 2,500 rpm, since the power curve of the engine is comparatively flat in this range. It was therefore decided that the propeller should limit the engine to approximately 2,500 rpm at full throttle. This would permit the use of the standard governor, result in greater gasoline economy afloat, and increase the life expectancy of the engine.

From the standpoint of marine propulsion, the largest practical propeller diameter was desirable. This was limited by ground clearance and space available for the tunnel and was finally set at 25 inches. The most effective pitch for this diameter proved in theory to be between 13 and 14 inches; this was substantiated in the tests. It was found that the horsepower available at 2,500 rpm would turn this propeller at a maximum of approximately 1,100 rpm, necessitating an over-all reduction from engine to propeller of approximately 2.3 to 1.

The use of first speed in the transmission was theoretically desirable. Coupled with the necessary overdrive in the propeller transfer case, this would give approximately the same maximum propeller rpm when reversing afloat, because of the fact that the transmission reduction would be about the same in first and reverse. However, it was not practical to use first speed since the first speed gears had a limited life expectancy, and second speed was selected as the second choice. The propeller transfer case was designed with the necessary overdrive to convert the output of second speed to the maximum usable propeller speed (1,100 rpm). Since the transmission in reverse had about double the reduction of second speed, the maximum propeller rpm available for reversing absorbed only about 50 per cent of the power used in driving ahead.

After several months of field operations with production models, it was decided to substitute an interchangeable, two-speed propeller transfer case, retaining the initial ratio for use with second speed for forward driving, and adding an overdrive of higher ratio, which provides approximately the same total reduction in reverse as in forward (Figures 10 and 11). In steep landings demanding the use of first speed for wheel drive, this provides the additional advantage of enabling the propeller drive to be put in the overdrive position for maximum propeller thrust.

The position of the propeller was determined as a compromise between moving it aft to increase efficiency and moving it forward to reduce its vulnerability.

FIGURE 10. Single-speed water propeller transfer case used in early models.

FIGURE 11. Two-speed water propeller transfer case used in later production models.

To simplify replacement and increase operating life, a replaceable journal with a sealed babbitt bearing was used in the outboard strut bearing of the propeller shaft and practically doubled operating life. A later development was a poured babbitt replaceable journal with seals incorporated on each end to exclude water and retain grease; a sand slinger, split to facilitate removal, was added; and the strut mounting on the tunnel was strengthened by the use of larger bolts and pads. Operating life was thereby quadrupled.

Some consideration was given to a retractable installation in which the propeller would operate with its lower blade 18 inches below the profile of the stern. This position gave about 0.4 mph additional speed, but it was felt that this increase was insufficient to justify the increased mechanical and operational complications and the increased vulnerability which would result.

Many modifications of *propeller tunnel* design were investigated to get the greatest propeller efficiency, vehicle speed, maneuverability, and ease in production. In the original design, the tunnel has vertical sides and sections resembling an inverted "U." It later was found advantageous to open out the lower edges of the tunnel in front of the propeller, slightly decreasing protection to the propeller but increasing speed, and for more maneuverability it was found necessary to open up the tunnel behind the propeller (Figure 12). To avoid unnecessary die work in production, it was desirable to retain simple curvature, and in the final design only the center portion of the tunnel has compound curvature (Figure 13).

The top of the propeller tunnel was located as high as possible without raising its outlet above the water line when the vehicle is unloaded. Any increase above this level results in air reaching the propeller when the vehicle goes into reverse, seriously reducing the thrust.

In an attempt to reduce the severe turbulence in the wake, the rear part of the tunnel top was sloped

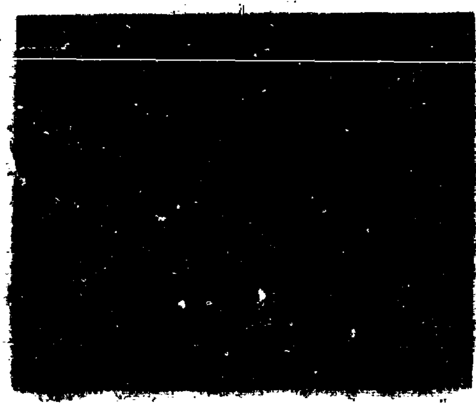


FIGURE 12. Final revised tunnel shape, propeller position, and rudder post angle.

FIGURE 13. Bottom view of hull, showing final design of propeller tunnel.

downwards, but tests showed that while this alteration improves the appearance of the wake, it reduces the speed of the vehicle.

Marine Steering

In the propeller tunnel of the original pilot model, the lower corners were designed to give maximum protection to the propeller and the rudder. The rudder was placed on the propeller shaft center line, rigged to turn a maximum of 40 degrees on each side of the center line, and controlled by ⅛-inch galvanized cables connected to a steel spool on the truck steering column (Figure 14).

Because of the large turning diameter, particularly when turning to the left, this design was changed by moving the rudder to the left of the center line, opening up the lower edges of the tunnel behind the center line of the propeller, and installing the rudder stock at an angle of 20 degrees forward and upward from vertical. Linkages (Figure 15) were introduced so that an equal number of wheel turns in either direction would have an equal effect in turning the vehicle.

Although this modification resulted in a considerable improvement, rudder response was slow and the rudder was found unbalanced, turning full right if the wheel were released. Later, an offset tab (Figure 16) was fixed to the rudder, eliminating the inherent tendency to swing to the right, and a new linkage system was developed to provide rapid rudder action for small movements of the steering wheel (see Figure 17).

Bilge Pump System

Early in the development of the DUKW, it was realized that because of the low freeboard desirable for satisfactory cargo handling, the probable use in surf, and the undesirability of cargo space covers, considerable quantities of water would be shipped during normal operations and consequently an efficient, high-capacity, foolproof bilge pumping system would

FIGURE 14. Rudder cable spool on steering column.

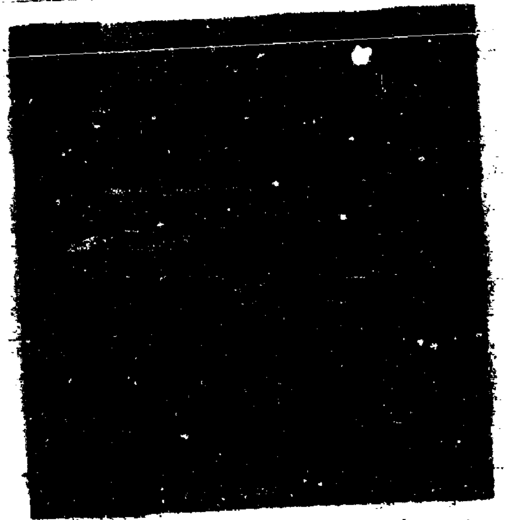


Figure 15. Original production rudder-control arrangement with linkages introduced to equalize turning circles.

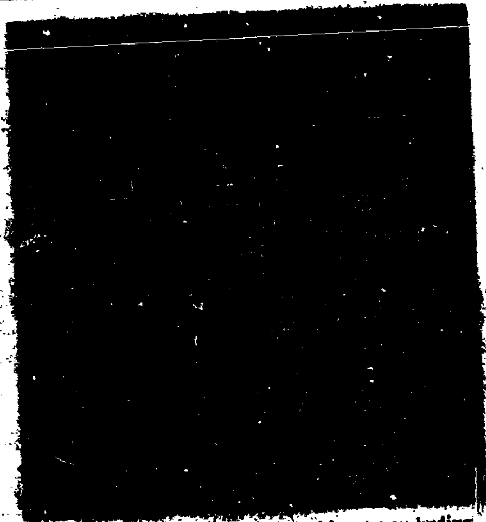


Figure 16. Revised rudder design with cutaway leading edge, rear tab, and sloping rudder post.

be essential. It was also realized that unlike a boat, which operates exclusively in water, the DUKW would spend much time on the shore, picking up not only cargo and personnel but also sand, dirt, and other foreign matter which would raise havoc with ordinary bilge pumps.

Three bilge pumps were specified: (1) a self-priming manifold pump, driven by the propeller shaft and used continuously to keep the separate bilge compartments dry; (2) a stand-by, high-capacity, centrifugal pump, also driven by the propeller shaft, which starts pumping when the water level in the center bilge gets deep enough to prime the pump; and (3) a hand pump for use when the propeller shaft is not turning or when the engine is stopped.

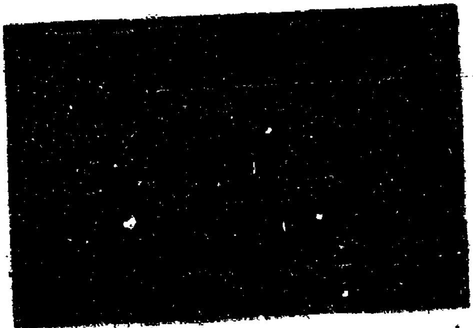


Figure 17. Quick-action rudder-control arrangement used in later production models.

The manifold pump, initially a belt-driven gear pump, unfortunately performed without failure throughout the pilot model tests but failed to stand up under field conditions. Because of the inherent vulnerability of this type of pump to sand and dirt, its need for very frequent lubrication, and the impracticability of necessary fine-meshed, protective screens, it was soon replaced by a Gould "water piston" pump. This latter device is not readily damaged by abrasion and can actually help clean out sand from the hull. Manual controls (Figure 18) enable the operator to use any or all of the intake lines.

The centrifugal pump used on the first pilot model was driven through a double V-belt drive, which was impractical and inefficient since it slipped when wet. This pump was later used with a single chain drive, which lacked transverse stability, and finally with a double chain drive, which gave a satisfactory capacity of 225 gallons per minute (Figure 19).

For the hand pump, a barge-type pump with a capacity of about 25 gallons per minute was originally strapped on the forward deck so that it would be readily accessible. This location, however, proved to be too exposed to heavy boots, and the pumps were frequently found squashed flat and inoperative when needed. Furthermore, such a portable pump can

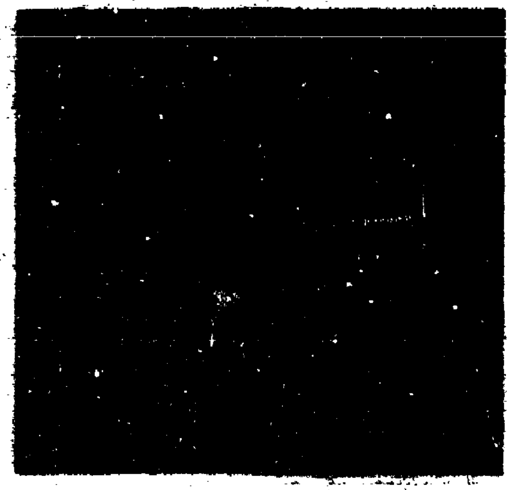


FIGURE 18. Manual controls for bilge pump manifold.

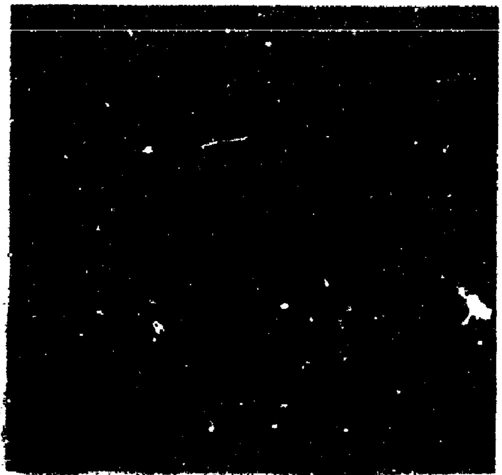


FIGURE 19. Gould pump with double chain drive.

rarely reach bilge water in the stern when the DUKW is fully loaded. An improved, built-in hand pump[1] was designed and recommended by OSRD in November 1943 and was approved with some modifications in June 1945 but never got into production.

It was recommended that all outlets for these pumps be visible to the operator so that he may know whether the pumps are working and whether the hull is leaking.

Hinged screens for bilge discharge were installed later to prevent foreign matter from dropping into the discharge pipes, and a small conduit was added to direct warm air on the bilge pumps and selector manifold in order to prevent freezing in cold-weather operations.

[1] See Table 2 in Chapter 4.

The final bilge pump system (Figure 20) has a total capacity of more than 300 gallons per minute—enough to cope with the water coming in through a 3-inch hole in the hull.

HULL DRAIN VALVES

Since drain valves or dump valves as used in military tanks had generally proved quite unsatisfactory, no such valves or sea cocks were installed in the original DUKWs. Instead, the bilge pump intakes were located close to the low points of the hull so that they would remove almost all of the water. This method, however, made the pump intakes too vulnerable to dirt in the bilge, and some water remained in the bilge at all times. Later, four drain valves were installed with extension handles (Figure 21), one forward of the front axle, one behind the driver, and one

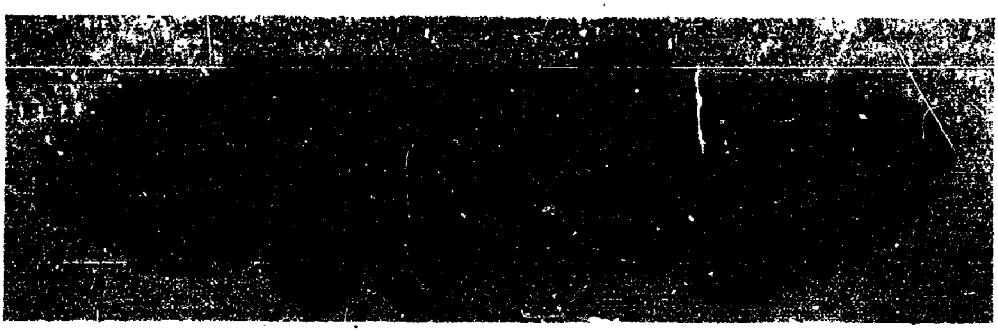


FIGURE 20. Bilge system in final production units, including three suction lines leading to pump under driver's seat and one line leading to pump under cargo floor.

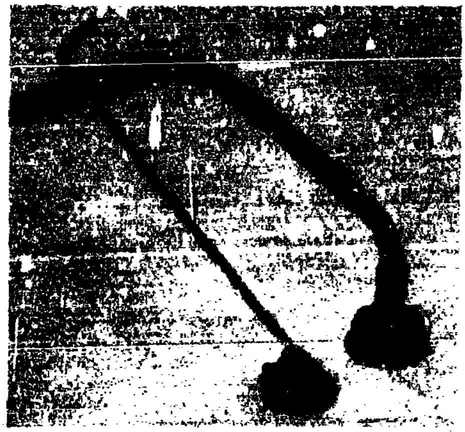


FIGURE 21. Drain valve with extension handle (left), shown with bilge suction cup (right).

in each bilge behind the rear wheel pockets. All handles can be reached without opening any hatches.

Water Sealing

Much study and testing were needed to devise means for keeping water out of submerged axle units and propeller shaft openings in the hull. Water operations resulted in an unusual difficulty by chilling the air in the axle housing so suddenly that the resultant high vacuum would force water past conventional seals. To prevent this, vents were provided in the form of rubber hose leading into the hull.

Double-lipped seals were installed on all pinion shafts, rear hubs, and pillow blocks. A major sealing operation was performed where the three drive shafts pass through the hull to the axles (Figure 22). The housings which enclose these shafts not only seal holes in the hull but also protect the shafts from obstacles and prevent entanglement with barbed wire and brush. These housings were modified several times to give increased clearances, stiffness, and accessibility.

A rubber sheeting was used first to seal the point at which the steering gear leaves the hull, with a double-lipped seal used on the shaft. A gasket with a clamp plate coated with sealer was used on later models.

The rudder and water propeller shafts are sealed by conventional marine-type stuffing boxes.

Some of the truck axle modifications originally ordered for the DUKW were later adopted for standard CCKW trucks to enable them to survive the "wading" involved in amphibious warfare.

Lubrication

The corrosive action of salt water on exposed bearings makes it essential to provide for frequent flushing and lubrication. Graphite bushings proved inadequate on control shafts and levers, making it necessary to add grease-gun fittings. The pillow block, originally an oil-filled housing, was improved by incorporation of provisions for grease-gun lubrication.

Engine Cooling

The DUKW cooling system is unusual in that air is drawn from behind the driver's compartment, pushed through the radiator, and exhausted through ducts on each side of the compartment (Figure 23).

Some fifty different combinations of fans, radiators, shrouds, and ducts were tried during the development of this system. Beginning with the standard CCKW truck radiator and fan size, the outlet ducts were enlarged, the shrouds improved, the fan increased in diameter, a fairing added ahead of the radiator, and the radiator moved ahead and finally increased in size. Despite the added size of the fan and the reversed flow of air, the power absorbed by the fan is no greater than that absorbed in the CCKW truck—about 8 hp at 2,750 engine rpm.

The fan, radiator core, and air passages were developed to provide balanced cooling when operating afloat at the torque peak of the engine (1,200 rpm) at an ambient temperature of 115 F. It was found, however, that cooling on land was between 5 and 10 de-

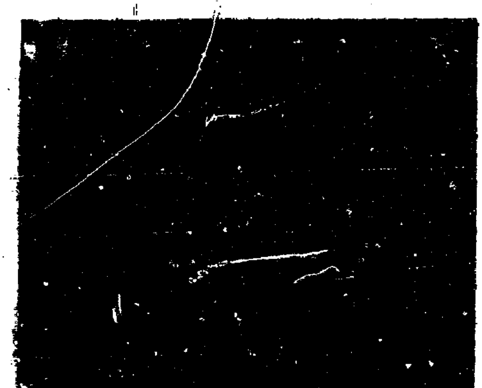


FIGURE 22. Housings for rear drive shafts.

grees less effective, and this was rectified by installing an auxiliary air intake scoop directly over the engine, to be opened as necessar , *during land operation only.*

Field operations indicated that the original intention was disregarded and that the auxiliary air intake was frequently opened during water operation, the result either of driver forgetfulness or of the need for additional cooling which resulted from neglect of some other parts of the cooling system. Water inevitably came through the opened auxiliary air intake and tended to create serious maintenance problems in the engine and electrical system. Carburetors, generators, exhaust manifolds, voltage regulators, and wiring all suffered. There were occasional accidents when the quantity of water would temporarily short out the engine. Consequently, production of the auxiliary air intake was discontinued at the end of the first year, additional specific instructions were issued to overcome temporarily unsatisfactory cooling, and cooling was improved by more complete sealing of the hot air outlet ducts, thereby reducing recirculation.

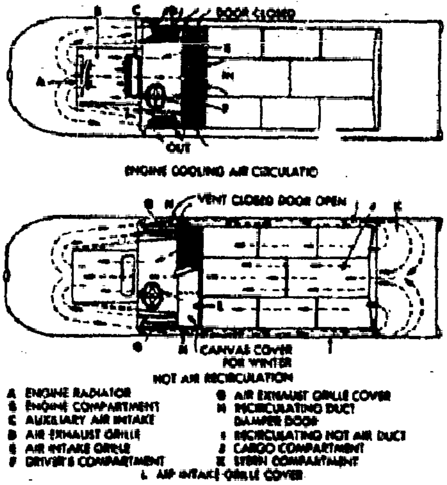


FIGURE 23. Diagram of cooling and heating system in production DUKW. Intake (C) shown on forward deck was soon permanently closed in the field and later removed in production.

Heating System

Frequently large bodies of water will remain open in freezing temperatures, and an amphibian operating under these conditions must be protected from water freezing in the bilges and piping and from spray freezing on the deck.

In the DUKW, the exhaust air from the engine cooling system is used as a source of considerable heat for cold-weather operations, since the air discharged from this system is generally at a temperature of more than 150 F, even in extremely cold weather. This air blows into the forward compartment and ordinarily is then discharged through ducts at each side of the cab. These outlets, however, are fitted with shutters which can close them to any desired degree; a canvas cover is also furnished to close the normal air intake grating; and, in addition, the cockpit coamings are extended below the deck to form a heating duct communicating with the engine cooling air outlets. If the dampers on each side leading to these coaming ducts are opened, the warm air is forced back to warm the hull sides, the side decks, and the cargo compartment, and then is discharged into the stern compartment and down below the floor to warm the bilge (Figure 23).

Other heating lines, running from the left air outlet passage directly to the bilge pumps and the forward bilge pump manifold, carry enough hot air to keep the pumps well above the freezing point.

A defroster, developed for both straight and sloping windshields, uses radiator fan exhaust air coming from the right-hand air outlet duct in the driver's compartment. This completely demountable unit is furnished in special kits and is not issued on all DUKWs.

The battery is located in the engine compartment in order to receive cool air in warm weather and warm, recirculated air in cold weather.

Tires

The CCKW truck, the parent vehicle of the DUKW, has 7.50x20 dual tires on the rear and intermediate axles, with singles on the front axle. This combination was tested on the first pilot model of the DUKW, performing relatively well on slippery mud but very poorly on sand.

Accordingly, sand tests were run on a number of identical CCKW trucks loaded to give DUKW axle weights and equipped with the following tire combinations:

1. 7.50x20 duals on rear and intermediate, singles on front—standard military snow and mud tread.
2. 8.20x20 duals on rear and intermediate, singles on front—standard civilian truck tread.

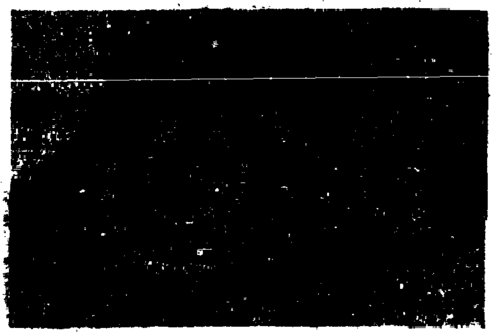


FIGURE 24. 11.00x18 ten-ply desert tread tires used on production DUKW.

3. General 38-inch Air Cats, singles—shallow diamond tread.
4. 10.00x20 singles, 12-ply—standard civilian tread.
5. 11.00x18 singles, 12-ply—standard civilian tread.

It was obvious immediately that neither the 7.50 nor the 8.20 duals could compare with any combination of single tires. The Air Cats gave the best all-around performance on sand and had low rolling resistance, but their great width made steering difficult and considerably reduced both maximum turning angle and water speed. They were also reported to be vulnerable to bruising and rim cuts.

The 11.00x18 appeared to be slightly better than the 10.00x20 and was finally adopted with 10-ply construction and desert tread (Figure 24). This, of course, entailed the production of special wheels, rims, and beadlocks.

An important result of these early tire tests was the doctrine of a particular tire pressure for a particular terrain—10 pounds pressure for soft sand, 30 pounds for coral, and 40 pounds for hard roads. Ample field experience later indicated the validity of this original doctrine, with the amplification that very soft terrain may require a pressure as low as 5 pounds.

Controllable Central Tire-Inflation System

To take advantage of these different pressures, it was necessary to provide an engine-driven, engageable air pump, which was made standard on all DUKWs (Figure 25). Two extension hoses were supplied so that two tires could be inflated at the same time. The use of this simple equipment, however, made it necessary to stop the vehicle and, under combat conditions, expose personnel to enemy fire. Accordingly, in July

FIGURE 25. Air pump used in central tire-inflation system.

FIGURE 26. Early proposed hub arrangement for central tire-inflation control.

FIGURE 27. Proposed two-line system, with housed, wire-actuated valve-in-stem.

1942, OSRD requested an investigation of centrally controlled inflation systems which could be operated from the driver's position while the DUKW was in motion.

At first, tests were conducted on a single-hose type with a two-way valve in the stem of each tire (Figure 26). The valve is opened by engine vacuum for deflating and by the tire pump pressure for inflating. Air enters through the external end of the hub and passes from a rotating hub gland through a copper tube to the tire valve. The tire valve is actuated by wire. This system was abandoned because the deflating air upsets the intake manifold vacuum.

The second system, also a single-line type, works on the same principle except that the escaping air in deflating is released to the atmosphere, and the valve is moved from the tire stem to the hub unit and actuated by a cam-operated bell crank.

The third (Figure 27) involves a two-line system, with pressure in one line for deflation and in the other for inflation, together with a housed, wire-actuated valve-in-stem, as in the first design.

All three of these systems, having individual valves, "fail safe"—that is, pressure is maintained in the tire even if the hose is torn off. None of these proposals was found sufficiently practical for use.

The final system, which was actually put into production, is a single-hose type with tire valve cores removed (Figure 28). A permanent air line leads to each tire through a rotating gland on each hub (Figure 29), permitting the driver to vary the pressure from the dashboard while the vehicle is in motion, either on land or afloat. All tires thus have equal pressure automatically. The system (Figure 30) includes an air pump running constantly with the engine, an air tank, a gage, a pressure regulator, a control valve for inflation and deflation, hose for emergency use or for inflating the tires of other vehicles, and six valves with which the driver can shut off the line to any tire (Figure 31). If an external line is damaged, the tire connected to it will go flat. As a safeguard to the remaining tires, any one line or group of lines can be segregated from the system by these internal valves operated by the driver. This system makes an ordinary tire fairly "bullet-proof." For example, 28 .45-caliber slugs were fired into a tire which, backed up by the compressor, maintained sufficient pressure for ordinary use.

BRAKES

Constantly submerged during water operation and periodically flushed with sand and salt water during surf and beach operation, the wheel brakes on the DUKW required considerable modification. The brake drums were mounted on the outside of the hubs to facilitate maintenance. Brake cylinders, end

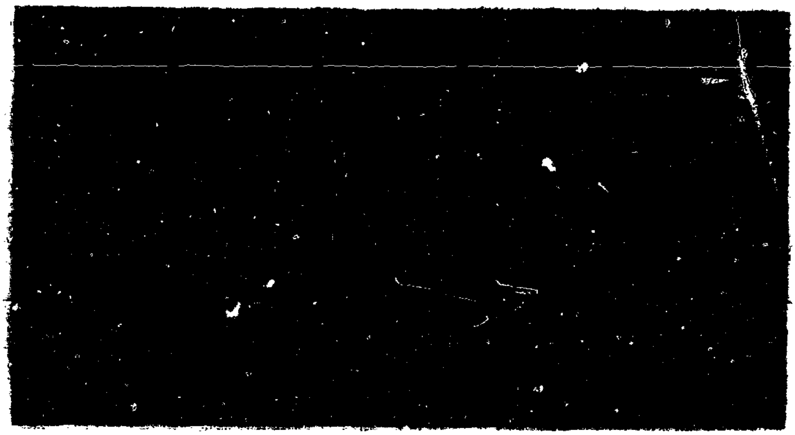


FIGURE 28. Single-hose, central tire-inflation arrangement adopted for production.

caps, and adjusting screws were plated with zinc chromate to resist corrosion. Brake return springs were rustproofed and the hooked ends improved. A search for a more suitable lining led to the selection of Thermoid 908-B composition, which represented the best compromise for stopping with either wet or dry brakes.

FIGURE 29. Cutaway of rotating gland used on each hub in final central tire-inflation system.

SUPERSTRUCTURE AND SURF PROTECTION

Early surf trials disclosed serious inadequacies of the superstructure, including the windshield, deck-mounted accessories, and cargo cover supports. First to fail under severe surf impact were the windshield and the surf plate: windshield frames bent and glass cracked, while surf plate braces bent, hinges tore loose, and plywood splintered.

A temporary field modification kit for the windshield was first designed for visibility over its top edge, but the surf continued to smash the partly exposed glass and to bend the metal (Figure 32). The modification kit was revised to extend full height, with peek holes for the driver (Figure 33), and this gave adequate protection. In the meantime, the windshield was redesigned and surf-tested, resulting in the sloping front and side panels finally adopted (Figure 34).

The first surf plate (Figure 35), made of unreinforced plywood, together with its piano hinges and brace rods, similarly failed under surf impact. The plywood plate was finally replaced by a reinforced steel plate, the brace rods were strengthened with a reinforcing channel, and the piano-type hinge was replaced by four heavy hinges (Figure 36).

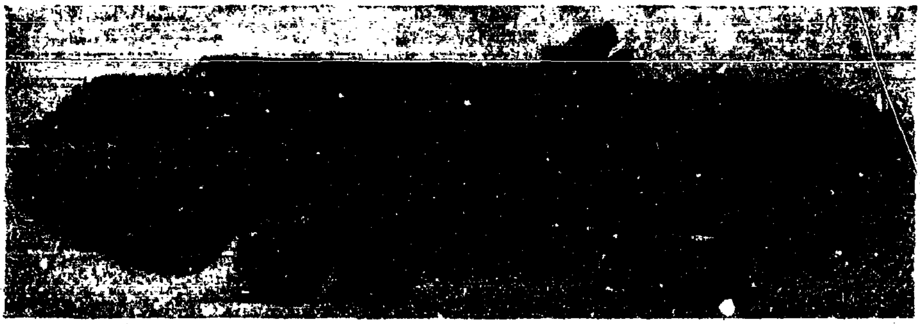


FIGURE 30. Central tire-inflation control system, including air pump, air tank, gage, control valve, and emergency hose.

The cargo bow, made of ash strakes joined with light sheet-metal stampings (Figure 37), likewise failed in operation, collapsing when hit by heavy surf. Ridge poles were issued as a temporary field modification, followed immediately by the substitution of an all-steel, tubular bow, strong enough to withstand surf impact (Figure 38). This new bow was sealed to make it float if lost overboard.

Since heavy following seas would occasionally roll over the coaming, it was raised at the rear and a plywood closure with side wings was added to resist the surf impact (Figure 39). The plywood structure, however, proved to be awkward and rarely needed and was replaced by a canvas closure (Figure 40).

In the initial design of the DUKW, no definite proposal was made for hull protection at shipside except for the specification of 12 fender eyes placed at random. Field tests soon indicated that more adequate

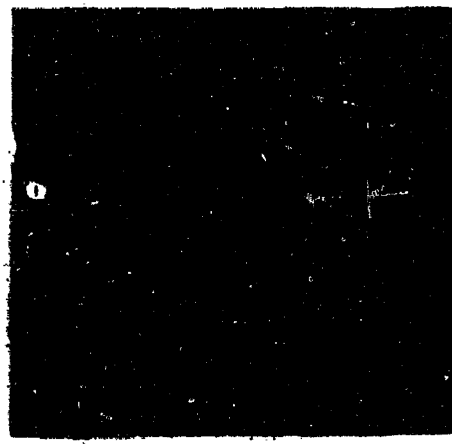


FIGURE 32. Effect of surf impact on windshield reinforced with early field modification kit.

FIGURE 31. Dashboard controls for central tire-inflation system.

FIGURE 33. Peephole windshield cover used as later field modification.

FIGURE 34. Final production windshield developed to withstand surf impact.

protection was necessary, and the original fender eyes were relocated and the number of fenders increased from 6 to 8. A system involving the use of 6x24-inch marine rope fenders was standardized, and the addition of a recommended ninth fender was approved.

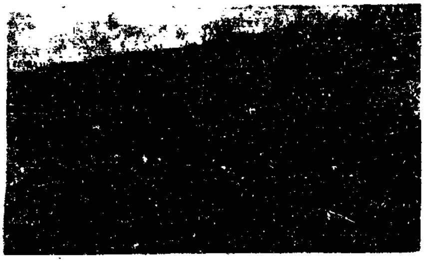


FIGURE 35. First surf plate made of unreinforced plywood and secured with piano hinges.

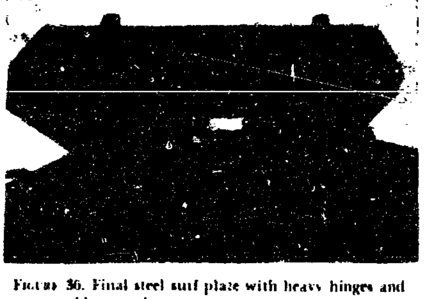


FIGURE 36. Final steel surf plate with heavy hinges and improved brace rods.

(This ninth fender was never issued.) The final production fender is a coir fender which can occasionally be worn out in approximately 1 day of operation. Although OSRD recommended in January 1943 that this be dropped in favor of a continuous rope fender in a chilled steel collar built in to follow the edge of the hull, the Army considered that the gains from this modification would be more than offset by the disruption to production, and turned down the change. Later experience indicated that the disruption in the field caused by the lack of this modification was no minor matter: the coir fenders were inherently unsatisfactory, the specified quality of the material was constantly revised downward, and the resulting maintenance problems were tremendous. A significant number of DUKWs suffered serious hull damage because of these inadequate fenders, an unnecessarily heavy load was placed on maintenance crews, and the total cargo carried by some DUKW companies was drastically reduced.

Lifting, Davit, and Mooring Eyes

Experiments were made with lifting slings adaptable to ship's boom handling and to ship's davits. Four lifting eyes were welded into the side of the deck and a set of davit eyes incorporated. Field tests indicated a need for a mooring eye, which was added amidships on each side.

Winch

The DUKW winch is similar to that on the CCKW truck except that it is located on the stern with lead

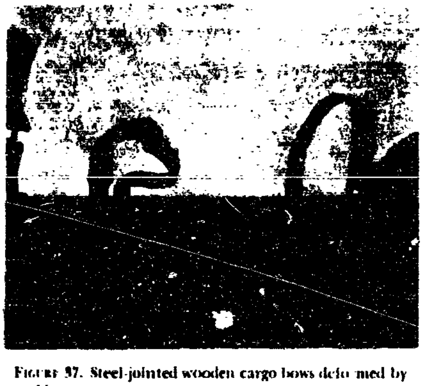


FIGURE 37. Steel-jointed wooden cargo bows deformed by surf impact.

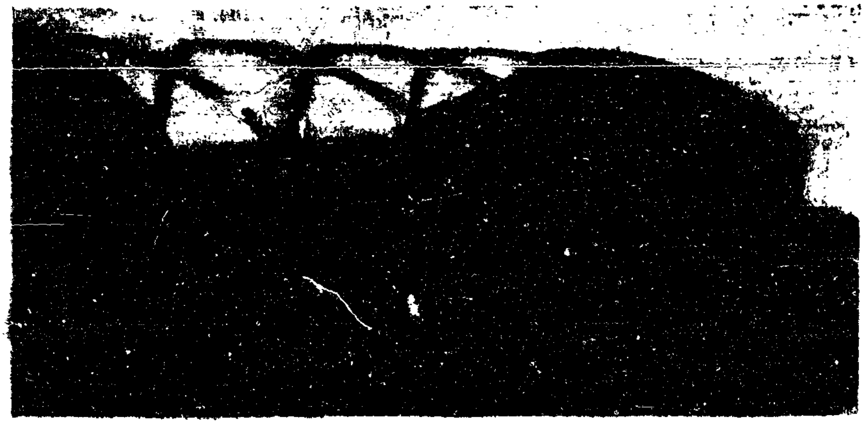


FIGURE 38. Final all-steel bows.

holes installed in the rear coaming and below the windshield, together with a fair-lead on the bow, to permit the cable to be led out either forward or astern. For better maintenance, the hole for the shear pin is made slightly larger and in later models the hatch in the rear deck is reversed, making the shear pin more accessible.

SAND ANCHOR

Tests of several types of anchor led to the selection of a 70-pound Danforth lightweight marine anchor for use in enabling a DUKW to free itself with its own winch as well as in anchoring at sea. This self-burying anchor is furnished as standard on all DUKW units.

ON-VEHICLE EQUIPMENT

In addition to equipment already discussed, the DUKW carries a large assortment of tools and spare parts. Initially there was little precedent to suggest what should be carried, but field tests and early tactical use quickly indicated the most necessary items. It was realized that if the DUKW were to be an important link in the establishment of a beachhead, it should not be handicapped by the absence of necessary tools. Also, since there would be no repair facilities for some time after a beach landing, certain spare parts should be carried on every vehicle.

As a result, pioneer tools, fire extinguishers, canvas buckets, a boat hook, and a large selection of hand tools are included as on-vehicle equipment. Spare

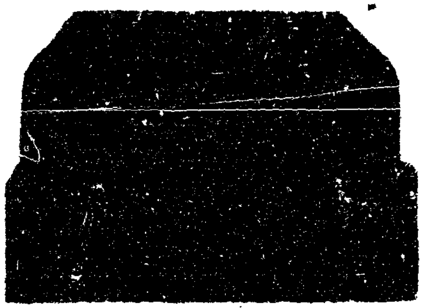


FIGURE 39. Rear plywood closure used in early models.

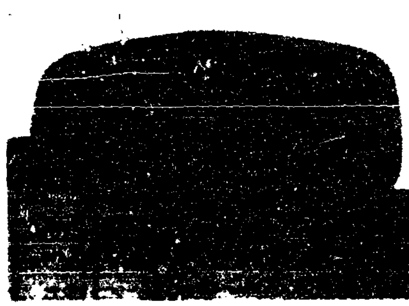


FIGURE 40. Rear canvas closure used in later models.

FIGURE 41. Side view of 1944 production DUKW.

parts include gaskets, drain plugs, rudder and winch shear pins, distributor parts, brake hoses, bearings, tire-inflation parts, pump chain links, set screws, keys, a hull patch plate, caulking compound, wire, tape, and sandpaper.

3.4 TEST PROCEDURE

Routine tests for performance and reliability were conducted during the early part of the investigation on the first pilot models and also on various components and proposed design modifications.

Measurements were made of maneuverability and speed on land and in water, economy, stability, grade ability, and general performance. Most of these tests were conducted at Crystal Lake, Pontiac, and at the General Motors Corporation Proving Grounds at Milford, Michigan. Special surf tests were conducted on beaches in Virginia, Massachusetts, North Carolina, and California, and tests over coral on the Florida Keys and later on Funafuti.

Throughout all tests, engine performance was carefully noted so that some temporary fluctuation would not lead to false conclusions on the efficiency of hull design or other components.

As noted above, major hull design changes were studied on scale models in towed and self-propelled tests.

FIGURE 42. Front view of 1944 production DUKW.

3.5 RESULTS

3.5.1 Design

The 1944 production model of the DUKW is illustrated by Figures 41 to 44, while Table 1 indicates the major differences between the first cab-over-engine pilot model built in 1942 (in 38 days from the "go ahead" order to the date on which it was driven out of the shop for field tests), the 1944 production DUKW, and the parent CCKW truck.[10,11]

Much help in the development of the DUKW was derived from the fact that many basic problems had already been solved in the conversion of the ¼-ton jeep into its amphibious counterpart.[j] In the DUKW program, building around a well developed basic unit made it possible for more than two-thirds of the parts to be incorporated as items well past the development stage and already of proved field reliability. The original basic design proved to be sound, and no

[j] See Chapter 2 in this volume.

FIGURE 43. Front and side view of 1944 production DUKW, showing shape of bow.

TABLE 1. Comparison of Specifications of 1942 Pilot Model DUKW, 1944 DUKW, and 1944 CCKW.

	1942 Pilot Model DUKW	1944 DUKW	1944 CCKW
Over-all length (in.)	358	372	270⅛
Over-all width (in.)	96	98	88
Over-all height—top and windshield up (in.)	99¾	106	109⅛
Over-all height—top and windshield down (in.)	84 11/16	89	76
Wheelbase (in.)	164	164	164
Ground clearance (in.)	17	18	17¼
Tread—front (in.)	60 7/16	63⅞	60 7/16
Tread—rear (in.)	67½	63⅞	67½
Cargo floor area (sq ft)	78	85	80
Tire size	7.50x20*	11.00x18†	7.50x20*
Engine displacement (cu in.)	269.5	269.5	269.5
Net engine horsepower (2,750 rpm)	93	93	93
Weight light (lb)	13,900	14,880	11,050
Weight of driver (lb)	200	200	200
Payload (lb)	5,000	5,000	5,000
Weight loaded (lb)	19,100	20,080	16,250

* Dual tires, rear and intermediate wheels.
† Single tires throughout.

major changes became necessary. OSRD, however, exerted the greatest possible pressure to eliminate those faults which, however minor, could nevertheless cause a vehicle to abort.[5]

[5] For a discussion of these modifications, see Chapter 5 in this volume.

3.5.2 Performance

LAND PERFORMANCE

In many respects the 1944 DUKW amphibian can equal, and in some cases surpass, the performance of the comparable 1944 CCKW truck (Table 2). Each vehicle has roughly the same maximum speed and minimum turning diameter; the angle of approach is greater in the DUKW, the angle of departure is less, and the DUKW can negotiate slightly less steep grades because of its greater gross weight (Figure 45).

Numerous field tests showed that the DUKW can operate successfully on hard roads and sand (Figures 46, 47, and 48). For sand operation, tire pressure be-

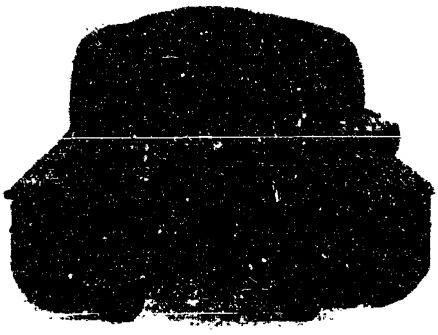


FIGURE 44. Rear view of early 1944 production DUKW.

TABLE 2. Comparison of Performance of 1942 Pilot Model DUKW, 1944 DUKW, and 1944 CCKW.

	1942 Pilot Model DUKW	1944 DUKW	1944 CCKW
Maximum land speed (2,750 rpm) (in mph)			
Reverse—low	2	3	2
Reverse—high	6	7	6
First—low	2	3	2
First—high	6	7	6
Second—low	4	5	4
Second—high	10	11	10
Third—low	9	10	9
Third—high	20	22	20
Fourth (direct)—low	16	18	16
Fourth (direct)—high	37	40	37
Fifth (overdrive)—low	20	22	20
Fifth (overdrive)—high	45	50	45
Maximum water speed (mph)			
Reverse	1	2.5	—
Second	5.4	6.4	—
Minimum turning diameter—land (ft)			
Left turn	68½	70	68½
Right turn	68½	68½	68½
Minimum turning diameter—water (ft)			
Left turn	110	40	—
Right turn	75	40	—
Angle of approach (deg.)	38	38	31
Angle of departure (deg.)	28	25	36
Maximum grade ability (%)	60	60	65
Cruising range, full throttle—land (approx.) (miles)	250	250	275
Cruising range, full throttle—water (approx.) (miles)	32	40	—

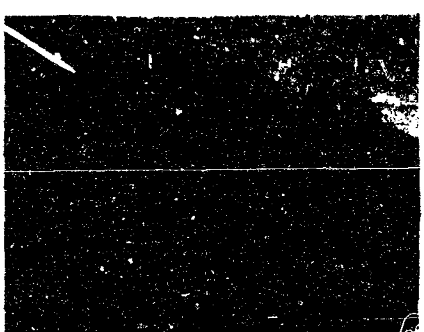


FIGURE 45. First pilot model DUKW climbing 60-deg. grade at Milford, Michigan.

comes of particular importance: a pressure of 30 to 40 pounds causes the tires to dig in, while a pressure of 10 to 12 pounds lets the tires obtain ample traction (Figure 49).

Operation on Coral. Even after military interest in the DUKW was well aroused, little thought had been given to the problem of driving this vehicle on coral

FIGURE 46. Desert tread tires, correctly deflated, enable DUKW to climb sandy hills. . . .

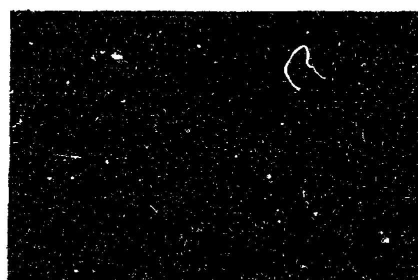


FIGURE 47. . . . . . . clear the summit . . . . . .

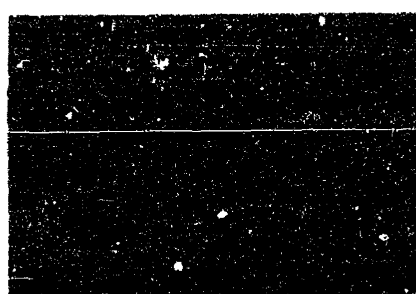


FIGURE 48. . . . . . . and go down the other side.

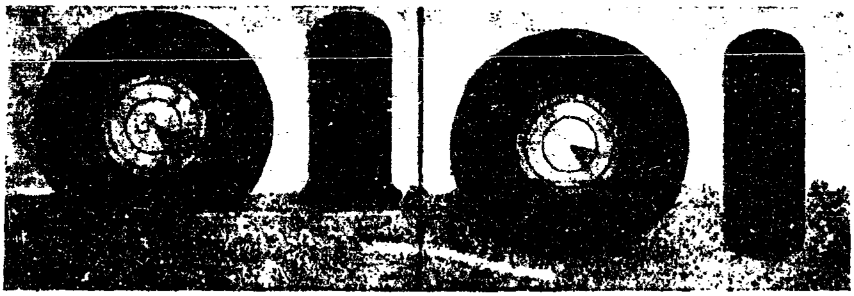


FIGURE 49. Diagram showing effect of tires in soft sand when they are deflated to about 10 pounds (left), as compared to tires at 30 pounds (right).

reefs, which front approximately 85 per cent of the shore lines in tropical Pacific waters. If DUKWs were to be used there, it was essential to learn how successfully they could be operated on such reefs.

Accordingly, in February 1943, OSRD conducted a series of tests with two DUKWs on various types of coral in the Florida Keys. These tests proved conclusively that, if a special coral-driving technique be carefully followed, a DUKW can be run almost indefinitely on the worst coral without serious damage to the tires or hull, and without additional wear attributable to coral (Figure 50).

Briefly, this technique involves the use of the lowest possible speed, considerable skill in selecting the best available route, and a tire pressure of 30 pounds. This figure was determined after a study of the effects of coral on tires inflated at various pressures. With too high pressure, it was found, the tire develops bruise breaks because of the weakness of the cords in the ply when under heavy tension. With too low pressure, the tire walls develop rim crushes and also sag so that they are exposed to shearing cuts. At 30 pounds, the tire is sufficiently soft to absorb the jabs of the coral points, and yet is firm enough that it is not forced against the wheel rim when passing over a sharp lip. In fact, when a DUKW is operated by a well-trained driver, the tires will receive less damage from coral reefs than will the tracks on a track-laying vehicle.

On the northern beaches at Okinawa, DUKWs were obliged to traverse several hundred yards of bad coral many times a day for 4 months. As a result of OSRD training and supervision, the drivers followed the standard operating procedure for this terrain and thereby prevented any increased tire wear attributable to coral.

Alternate Gear Combination. During the early phases of the development, it was felt that more effective power was needed to improve beach performance. Since the engine could not be readily changed, an alternate gear combination was considered in

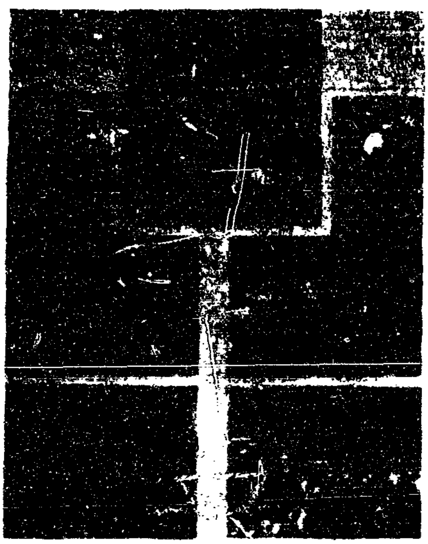


FIGURE 50. DUKW tires at 30-pound pressure successfully cross coral in tests on Florida Keys.

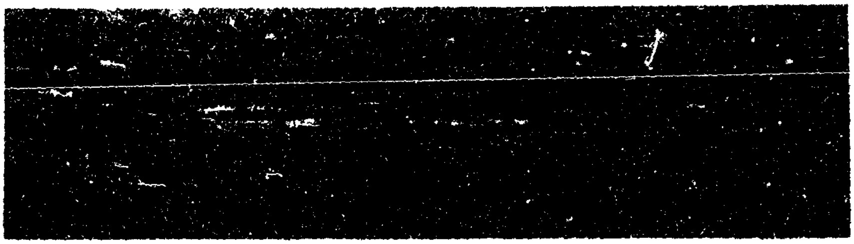


FIGURE 51. Minimum turning diameter in water is 75 to 140 feet for 1942 pilot model DUKW, 40 feet for production model shown here.

order to give lower ratios with the otherwise standard transmission.

The approximate comparative road speeds to be obtained with the two types is shown in Table 3, with power in approximately inverse proportion to the indicated maximum speeds:

TABLE 3. Maximum Load Speeds (mph) at 2,750 Engine rpm.

	Standard CCKW type		Proposed "underdrive" type	
Gear	High	Low	High	Low
5th	50	22	40	18
4th	40	18	23	10
3rd	22	10	13	6
2nd	11	5	9	4
1st	7	3	6	3
Reverse	7	3	7	3

Although the recommended alteration was not approved for reasons of production, maintenance, and driving simplicity, and because the change in tires gave improved sand performance with the CCKW transmission, the wisdom of this decision was later questioned.

In retrospect, particularly in view of the heavy overloads which were habitually carried and the increased hull weight, it appears that the nonstandard, "underdrive" transmission would have been more desirable. The CCKW shift pattern is unusual and relatively inconvenient. There would be less spread from the ratio of second speed to reverse. The lower ratio second speed would frequently obviate the necessity of using first speed, except when the vehicle is stuck. The lower ratio transmission would provide speeds better suited to the majority of landing operations. Although the present transmission provides a theoretical top road speed of 50 mph, this is practically never used under field conditions.

WATER PERFORMANCE

The water speed of the DUKW, greatly affected by the resistance of the hull and the various appendages, was increased by about 30 per cent as a result of design improvements. In preliminary tests, the maximum speed was 5.0 mph. Decreasing the size of the propeller increased it to 5.35. Reducing the power requirements of the fan, introducing down draft carburetion, tuning up the engine, and adjusting the valves brought it up to 5.75. Adding 18 inches to the stern and moving the propeller 15 inches astern increased it to 6.3. Providing covers for the front wheel houses increased it to 6.4. And, finally, improving the propeller and drive ratio brought it up to 6.5.

A further increase of perhaps 0.4 mph could theoretically have been obtained by using a retractable propeller, but it was felt that the actual net average gain for a DUKW fleet over a period of time might be nil, as a result of the probable frequency of damage to the blades. Further increases up to 0.4 mph could theoretically have been made by omitting the governor, using a slightly different shape of propeller, and adding additional fairings and covers, but these changes would have involved too many mechanical and operating difficulties.

The turning circle of the production DUKW in water—about 40 feet—is larger than that of some other landing craft, but is not excessive for maneuverability (Figure 51).

Surf Performance. Many field tests proved the ability of the DUKW to negotiate quiet lake water, open sea, and surf. When the vehicle is operated by a trained driver, it can get through a surf up to 15 feet high, and in tests has gone through surf somewhat more than 20 feet high without difficulty.

The DUKW was repeatedly found to be inherently stable in the surf. Its center of gravity is low, largely

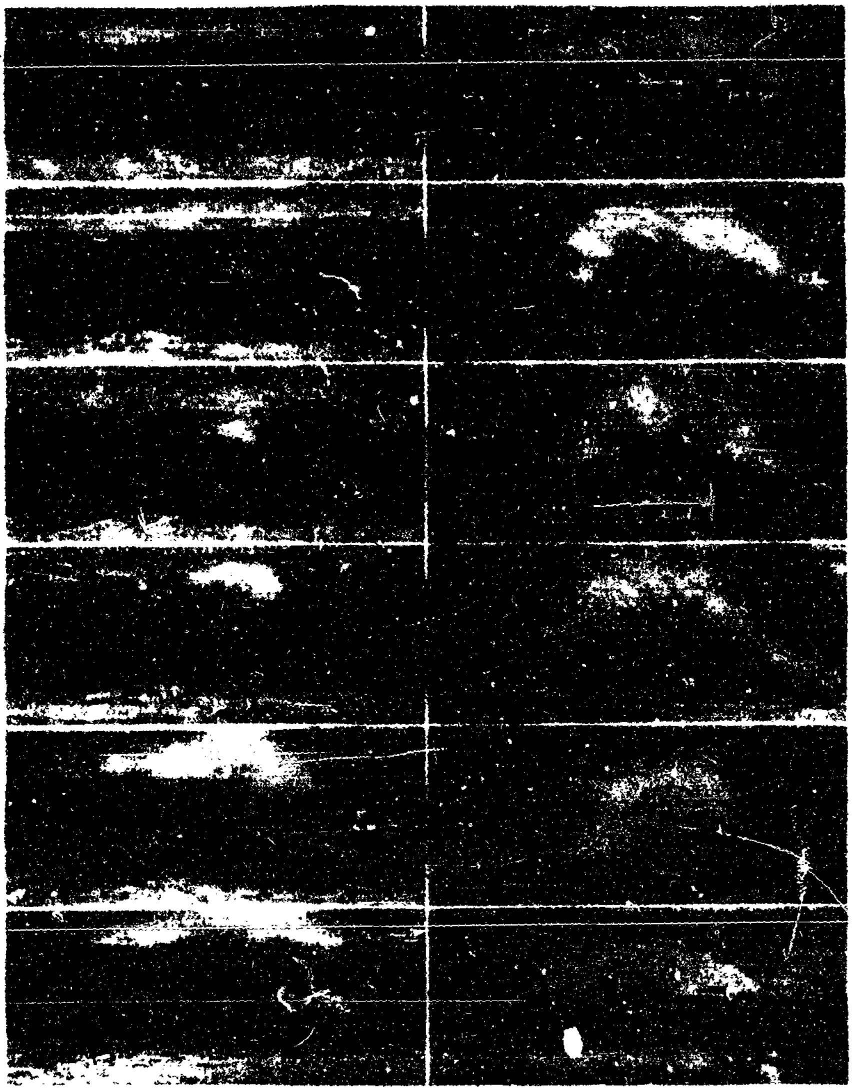


FIGURE 52. Series of photographs of laden DUKW penetrating 15-foot comber on steep-to beach at Monterey Bay, California, showing very rapid rise of bow due to shape and buoyancy of bow sections. Last picture shows course unaltered. Amount of water taken aboard is ejected by pumps in about 1 minute.

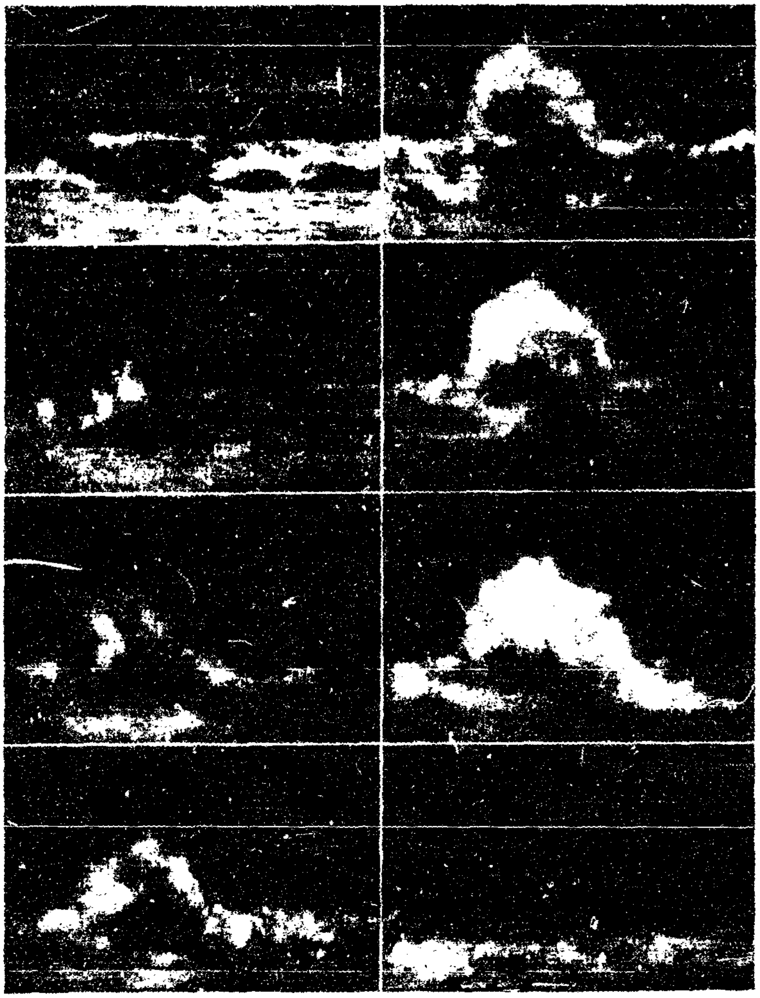


FIGURE 53. Series of photographs showing laden DUKW standing out through solid afterbreak of 15 foot comber on steep-to beach at Monterey Bay, California. Course is deliberately somewhat diagonal and is unaltered. Speed is temporarily reduced from about 4 knots to about 1 knot.

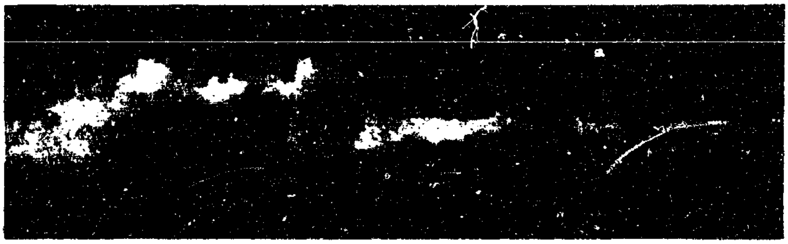


FIGURE 54. DUKW surf ability tested in moderate surf at Monterey Bay, California.

as the result of the location of three heavy axles below the bottom of the hull. Its deck weight is light and its cargo rests in a relatively low position. Its hull has extremely full and well-balanced ends. Displacement is large as compared to freeboard and, as a result, the DUKW can go through a wave which would knock a lighter boat toward the beach.

When the DUKW lands with the surf, the hull resistance created by the numerous appendages holds the vehicle down to a safe speed. It seldom goes very far on one wave, although in extreme cases it has gone somewhat more than 100 yards. Rudder steering is used during a landing, and the front wheels provide some steering when the propeller and the rudder may be temporarily out of water. The low reserve buoyancy minimizes any tendency to lift the rudder or propeller. As shallow water is reached, stability is derived not only from the fact that there are wheels along each edge but also from the ability to steer at each end—with rudder in back and wheels in front.

The major surf tests were conducted off Kitty Hawk, North Carolina, on June 25, 1942; near Provincetown, Massachusetts, in November and December 1942; off Virginia Beach, Virginia, in January 1943; and off Fort Ord, California, in January and March 1943.

Off Kitty Hawk, the tests were run on the first pilot model in a 6-foot surf. The engine ignition system was not waterproofed, the cab-over-engine structure exposed the engine, and the steering was inadequate. As a result, the DUKW came broadside to the surf and the engine was drowned out, but the DUKW was not swamped. It was retrieved and driven across country to Pontiac, Michigan.

In the tests at Provincetown and Virginia Beach, an improved model was used in a 7-foot surf and operated quite successfully, making repeated trips in and out of the surf. Major failures were the windshield and bow surf plates.

At Fort Ord (Figures 52 to 54), DUKWs with still more improvements were used in OSRD-supervised training in 15-foot surfs and, in tests, in higher surfs, and again operated successfully even under these conditions. Windshield, bow surf plate, and cargo bow failures still occurred but were finally minimized by modified structures.

Possibility of Strategic Surprise. These tests and the improvements they brought forth soon became of paramount tactical importance, since they made it possible for the DUKW to be used in a surf so heavy that no other amphibian or boat could operate. Both American and British Services were thereafter repeatedly urged to plan operations around this ability of the DUKW and to land at places and in weather which the enemy would certainly consider impossible for landings, thus achieving tactical and possibly strategic surprise.

3.6 ACCESSORY EQUIPMENT

The mechanical development of the DUKW was accompanied by the conception of several special missions for which the new vehicle could be employed. In many of these cases, special equipment was designed and constructed to facilitate loading and unloading the DUKW, to enable the DUKW to ferry tanks and trucks, and to adapt it to combat operations. In some cases, the equipment was designed but, because of changing military requirements, not investigated further. In others, the equipment was designed and built but not approved,

or approved but not put in production, or put in production but never delivered to the forward areas. (See Chapter 1.)

In the case of such of those missions as were carried out in the field, standard operating procedures were developed on the spot in collaboration with the Services.

5.6.1 Cargo-Handling Equipment

A-FRAME

In November 1942, a tactical doctrine was developed whereby DUKWs would carry 105-mm howitzers from ship to shore, unload them by A-frames, and tow them into battery position. The first such A-frame was improvised in the field for the Provincetown, Massachusetts, demonstration (see below) from cedar timbers with temporary steel fittings (Figure 55). This was soon improved and an A-frame made of round steel tubing went into production (Figure 56). Few of these production A-frames reached combat areas in the European and Mediterranean theaters before V-E Day, however, and the A-frames actually used in those areas had to be improvised on the spot from whatever materials were at hand.

PALLETS AND PALLETIZED LOADS

In order to obtain maximum use of the DUKW cargo space and to facilitate cargo handling, a DUKW pallet was designed early in 1943. This pallet consisted of a wood platform with canvas webbing sides to contain the cargo and a four-part wire sling on a lifting ring. Later, since webbing was almost unobtainable, it was replaced by rope net.

Tests proved that this pallet was of some help to DUKW cargo-handling operations but it received only little interest. In spite of its advantages, it was elaborate and bulky, and it still did not solve two of the main problems: easing the burden of cargo-handling personnel at the ship unloading point and speeding up the flow of cargo during the assault phase of an amphibious operation.

At this time, however, some interest was being shown in the palletization of certain assault cargo, such as field rations and ammunition, by securing it with steel strappings to a wooden platform mounted on runners. Palletized loads could be made up at the ports of embarkation or even at the factories, making it possible to save manpower and time in the forward areas where these factors were most vital.

In several operations, a limited amount of palletized cargo was used with great success, but this was strongly opposed by the Navy because the bulk of the pallet itself reduced the amount of supplies that could be carried in a ship. With the greater availability of shipping in 1944, however, more demands for palletized loads were made and in the Kwajalein operation the majority of rations, ammunition, and fuel were palletized.

The dimensions of the pallet had been set at 48x72 inches, but these were not ideal since only two loads could be fitted into the DUKW cargo space. Another objection was based on the excessive amount of wire cable required to make the two slings for lifting and towing each load.

Accordingly, a new palletized load was developed by OSRD at Oahu early in 1945. This load had over-all dimensions of 44x70 inches, which enabled three loads to fit into a DUKW. It was found, incidentally,

FIGURE 55. Emergency A-frame improvised from cedar timbers for demonstration at Provincetown, Massachusetts.

Figure 56. Steel tubing A-frame adopted for production, shown here with improvised outriggers attached to DUKW to provide added stability for "A framing" afloat.

that these dimensions were also better suited to a variety of other carriers, such as the 2½-ton truck and the LVT(4). To dispense with permanent slings on each load, lifting eyes were fitted at each of the four corners, making it possible to lift the load with a four-part sling which was unhooked and remained on the cargo hook (Figure 57).

A variety of supplies palletized in this manner were demonstrated on Oahu to staff representatives, and the system was approved by Headquarters, U. S. Armed Forces, Pacific Ocean Areas, and later by Headquarters, Army Forces, Pacific. It was not put into use, however, before the end of World War II.

Transfer Rigs

When DUKWs began to operate on a large scale on big land masses, it was found that their amphibious values were often being largely wasted and, particularly when the unloading points were more than 4 or 5 miles inland, the amphibians were spending most of their operational time as land trucks. In such cases, an excessive number of DUKWs was required to maintain a cycle which would not cause delay in getting the cargo off the ships.

Consequently, a standard operating procedure was developed, based on the use of a transfer point system so that loads could be transferred from the DUKW to a land truck close to the DUKW landing point and the trucks then used to make the long haul. Several types of transfer rig were used, the commonest being 5-ton mobile cranes and DUKW A-frames (Figure 58). DUKWs deadlined for water operation because of propeller or hull damage could be used as transfer rigs so that seaworthy DUKWs would not be tied up.

Figure 57. Palletized cargo being loaded into DUKW at Oahu with aid of four-part sling.

Other rigs included a high lift on a truck, a high lift on a platform, and an A-frame on a land truck. In the Normandy landings, several of these types of transfer rigs were used on a large scale. In addition,

Figure 58. Mobile crane lifts cargo from DUKW; simple transfer rig used in Southwest Pacific.

FIGURE 59. Transfer rig arrangements used to transfer cargo from DUKWs to trucks in Normandy landings.

a steel pipe platform developed by the Transportation Corps was service-tested at Omaha Beach. At Okinawa, this standard operating procedure had become accepted and land hauls of more than 2 miles were made by truck. (See Figure 59.)

3.4.3 Ferrying Equipment

During the early part of the development program, considerable emphasis was placed on the design and testing of many types of ferrying equipment. Particular interest had been expressed by the Chief of the Armored Force in the possible use of DUKWs to take light or medium tanks from shipside across water, sand bars, and coral reefs to a beachhead. Accordingly, and as part of a systematic exploration of all fields in which DUKWs might be useful, tests were carried out with various types of cargo and with various types of ferrying equipment.

These were never exploited beyond the experimental stage, because better means for doing the same thing were developed by the Armed Services.

WET FERRY

Preliminary analysis indicated that a pair of DUKWs should be able to ferry a light tank through water without difficulty. With two DUKWs forming a catamaran, being held in position with compression struts at the decks and tension cables crossed from the lowest corners of the hulls, trials were conducted in a fairly shallow lake at the General Motors Proving Ground in September 1942. A light tank was equipped with necessary sealing devices, attached to the DUKWs (Figure 60), carried across the lake (Figure 61), and discharged on the other side (Figure 62).

Later, at the request of the Ordnance Department, similar trials were made with the medium tank, first in a lake and then in deep water. In the final trials off Fort Story, Virginia, preliminary runs were made with a dummy tank—four large water containers with quick-action dump valves. When these boxes were filled with salt water, they and their supporting platform weighed about 42,000 pounds, which represents approximately the negative buoyancy of the

FIGURE 60. Light tank being connected to two DUKWs for wet ferry across Sloan Lake at General Motors Corporation Proving Grounds, Milford, Michigan.

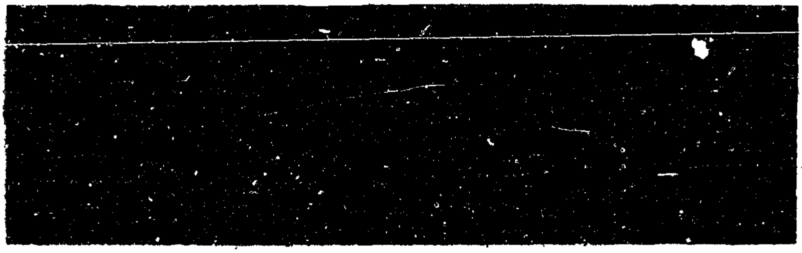


FIGURE 61. Wet ferry under way.

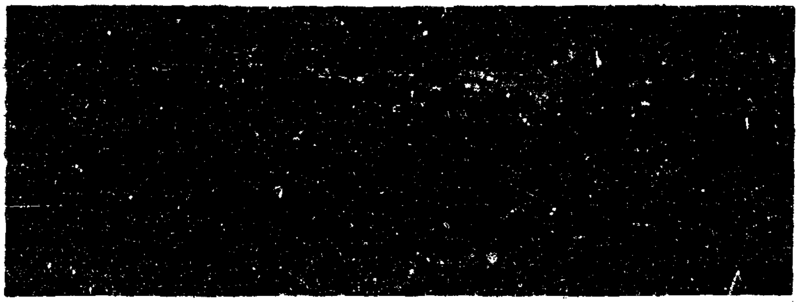


FIGURE 62. Wet ferry completed: light tank climbing to dry land.

medium tank. Sea trials showed the DUKWs could handle this load, but with little reserve buoyancy (Figure 63).

A waterproofed medium tank was then attached to the DUKWs, carried to a ship standing more than a mile offshore, hoisted aboard, lowered again, and carried back to shore (Figures 61 to 67).

Since the reserve buoyancy was dangerously low, however, a serious leak in any one of the three units would have been disastrous. The lack of freeboard

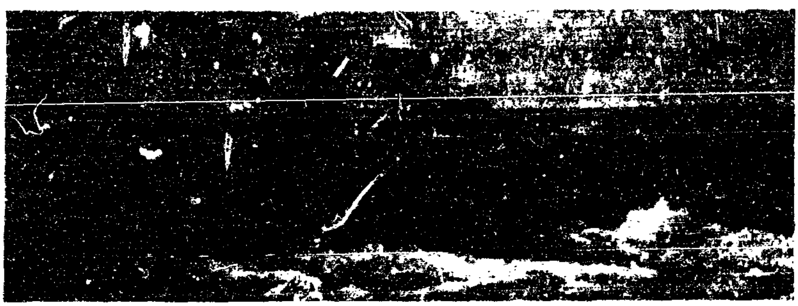


FIGURE 63. Rehearsal of wet ferry off Fort Story, Virginia, with boxes of water as test load.

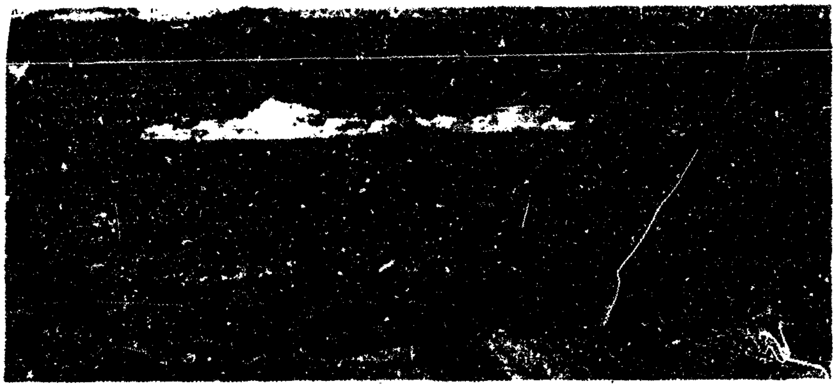


FIGURE 64. Wet ferry test: medium tank supported by two DUKW's leaving beach at Fort Story.

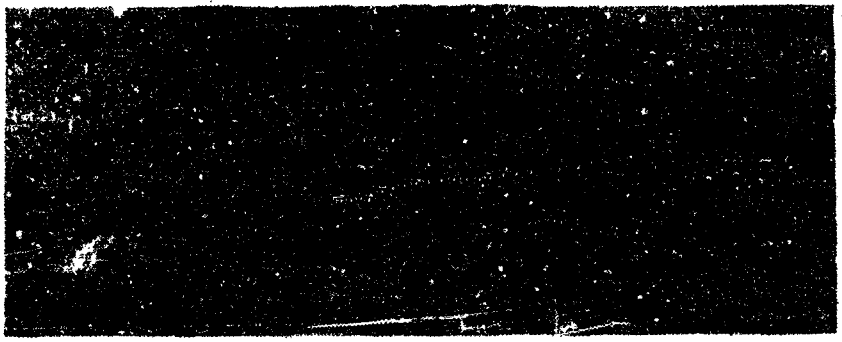


FIGURE 65. Ferry and tank nearing ship more than 1 mile offshore.

FIGURE 66. End of ferry ride: tank at ship's side and sling made fast.

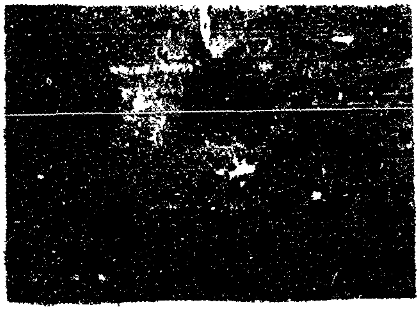


FIGURE 67. Tank leaving DUKW ferry on way to ship's deck.

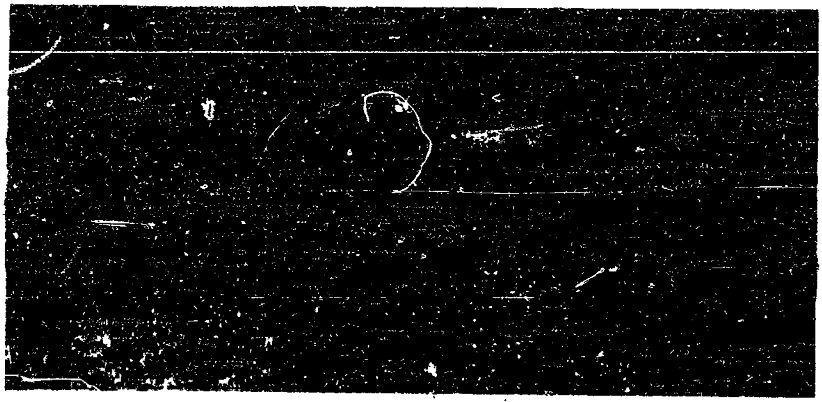


FIGURE 68. Catamaran and treadway for dry ferry.

would generally limit operations to relatively smooth water, with a maximum wave height of about 2 to 3 feet. The project was ultimately dropped.

Dry Ferry

It soon became evident that nonsubmersible vehicles and goods could be ferried over deep water by using platforms or treadways erected on the same catamaran rig used for wet ferrying. Several types of treadways and loading ramps were designed and tested, with the best design providing a long loading ramp with the pivot point amidships so that the load is shared by all axles. The DUKW winches are used to raise the ramps, which then lock to front deck pintle hooks to form the sea-going platform.

At sea trials off Fort Story, Virginia, the improved

FIGURE 69. Army 6x6 truck backing up treadway for dry ferry test off Fort Story, Virginia.

FIGURE 70. Truck at sea in test of DUKW dry ferry.

FIGURE 71. Platform ferry requires simple equipment generally available in field.

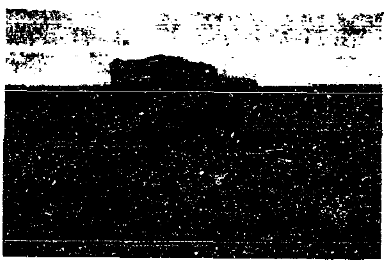


FIGURE 72. Platform ferry entering water.

rig was used in one test to carry a 6x6 truck from the beach to a ship standing a mile offshore (Figures 68 to 70), in another to carry an armored half-track, and in a third to carry an M-3 light tank weighing about 28,000 pounds. Reserve buoyancy was very low.

Platform Ferry

As a field improvisation, a platform was built across two DUKWs, which were then rigged together without use of special pintle hooks or reinforcements. The vehicles were lashed together at bow and stern by cables and turnbuckles, separated slightly by spacer blocks, and then used to support a platform laid across the cargo coamings and stabilized by timbered rails and cross rails secured to lashing eyes in the cargo space. The platform, which was designed and built in 3 days, successfully carried an armored half-track truck in deep water (Figures 71 to 72).

Airplane Ferry

In September 1943, after the DUKW had been accepted and used routinely for cargo carrying, a request was made by the Army to adapt this vehicle for ferrying the P-38 twin-engine and the P-40, P-47, P-51, and P-63 single-engine fighter planes from ship to shore.

The basic catamaran construction, similar to that used earlier in the wet ferry for tanks, was employed in this new assignment, but with a greatly increased span necessary to accommodate the airplane's landing wheels. For structural reasons, the plane was sup-

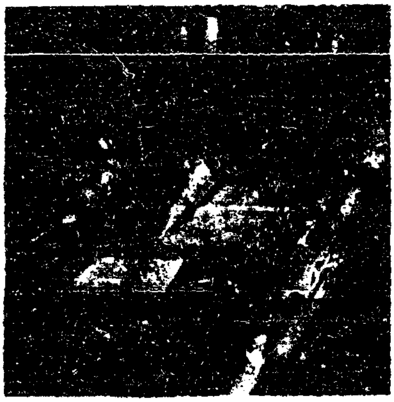


FIGURE 73. P-38 fighter plane stowed on ship's deck with wing tips removed.

FIGURE 74. P-38 being lowered to waiting DUKW ferry off Hampton Roads, Virginia.

FIGURE 75. P-38 secured on DUKW ferry.

FIGURE 76. DUKW ferry heading for beach.

ported in troughs secured to the sides of the DUKW hulls. These troughs also acted as runways for rolling the plane to the stern, where specially designed ramps continued the treadway to the ground.

With the P-38, it had been believed at first that the plane could not be safely loaded or unloaded with its wing tips in place, and these were removed for the first trials (Figures 73 to 77). Later trials showed that a better procedure is to moor the DUKW's stern to the side of the ship, and in this position, since wing span is not critical, the wing tips can be left in place (Figures 78 and 79).

These tests indicated that not only the P-38 but also other fighter planes could be ferried successfully.

FIGURE 77. P-38 rolling down ramp to beach after DUKW ferry trip.

FIGURE 78. Modified mooring arrangement makes possible handling P-38 fighter plane with wing tips in place.

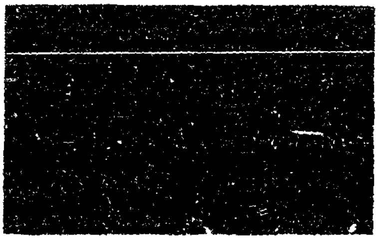


FIGURE 79. P-38 with wing tips in place on way to beach by DUKW ferry.

TRACTOR-TRAILER

At the request of the Ordnance Department, rough plans were prepared for a large amphibious tractor-trailer to increase the capacity of the DUKW. Sketches were prepared for a two-wheeled, stern-ramp trailer, the necessary modifications to the DUKW stern, and a suitable hitch (Figures 80 and 81), but no detailed plans were made and no pilot model was constructed. A smaller amphibious trailer, however, was designed and one test model was constructed.[1]

[1] See Chapter 8 in this volume.

3.6.3 Ponton DUKWs

In an attempt to provide a stable, powered unit for heavy-duty dry rafts and floating bridge supports, designs were prepared for coupling two DUKWs together, first stern-to-stern and later bow-to-stern. This would provide a self-propelled unit, thus eliminating the need for extra transportation on land and for maneuvering cables and power boats or outboard motors in water. Test units were constructed (Figures 82 and 83) and taken to the Imperial Dam on the Colorado River for study. As in the case of ferrying tanks and airplanes, the DUKWs were not seriously considered for use as pontons because of their greater need in other operations.

3.6.4 Mat-Laying Equipment

In May 1943, methods were developed for enabling the DUKW to lay a woven accordion-pleat wire land-

FIGURE 80. Artist's conception of proposed amphibious tractor-trailer unit.

FIGURE 81. Artist's conception of proposed tractor-trailer unit at shipside.

ing mat[m] somewhat similar to that used for air strips but much lighter. Its primary use would be to provide landing strips from the water's edge across soft sand for the support of vehicles normally unsuited to soft sand operation. Presumably these matting strips would be laid by a DUKW just ahead of landing craft approaching the beach. The mat-laying device might also be used for laying a temporary take-off strip for airplanes engaged in emergency ferrying operations.

In operation, the landing mat (Figures 84 and 85) would be drawn from its folded position in the rear, passed over the cab, and then spread under the front wheels by the forward motion of the vehicle. The mat would have to be hand-fed until the first section passed under the front wheels, after which the forward motion of the vehicle would furnish the necessary feeding power. Brake shoes on each side of an overhead guide frame would regulate the tension at which the mat would be laid. It was calculated that

[m] Developed by Tri-State Engineering Company, Washington, Pa.

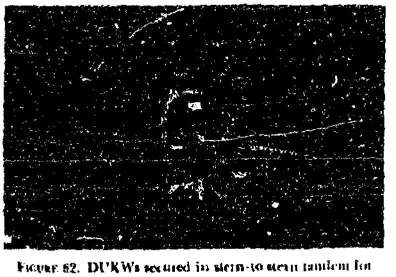


FIGURE 82. DUKWs secured in stern-to-stern tandem for ponton tests.

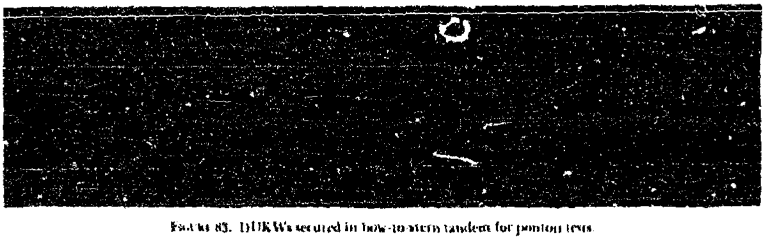


FIGURE 83. DUKWs secured in bow-to-stern tandem for ponton tests.

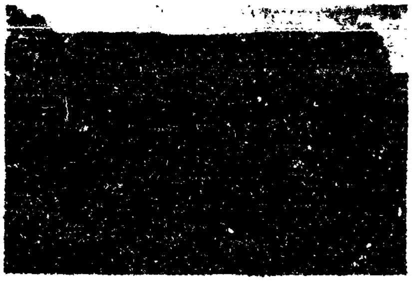


FIGURE 84. Front view of DUKW equipped with proposed landing mat.

one DUKW could lay from 200 to 400 feet of matting, depending on the roughness of the sea and other external conditions.

Preliminary engineering tests were conducted on the use of this device on the DUKW, but it was neither subjected to routine tests nor used in actual operations.[4]

2.4.5 Armament

GUN RING

A gun ring mount already developed for trucks was adapted for the DUKW (Figure 86) by the War Department.

THE 105-MM HOWITZER

The successful use of the DUKW in transporting various weapons led naturally to the proposal that these weapons be so installed that they could be fired at sea or used as mobile artillery on land.

After a protracted study with the 4.2-inch chemical mortar, it was found that this weapon could not be fired on the DUKW without the installation of a complicated, elaborate shock-absorbing system. Major emphasis was therefore placed on the 105-mm howitzer, and early in 1944 preliminary tests on an improvised harness were undertaken, first on land and then at sea (Figures 87 and 88). The results were sufficiently encouraging for OSRD to recommend further development and adoption of this combination as a major addition to amphibious fire power. This recommendation, however, was tabled partly because of the expectation by the using Services that the LVT(A)(4), a larger and armored vehicle, would soon be available and would be superior to the DUKW, and partly because of human inertia. It

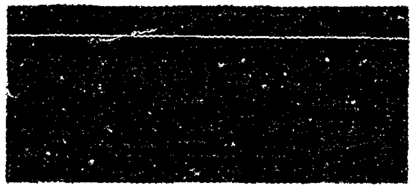


FIGURE 85. Side view of DUKW equipped with landing mat.

was later found that the new LVT, when it was finally delivered, could carry only a 75-mm weapon.

Had the OSRD recommendation been accepted without delay, 105-mm fire power in DUKWs would have been available for atoll warfare from Kwajalein on.

THE 25-POUNDER

A similar harness for firing the 25-pounder, the British counterpart of the 105-mm howitzer, was developed in India for use in an operation which was later cancelled. This form of amphibious fire power was not subsequently used, being superseded by rockets.

THE 3-INCH ANTITANK RIFLE

A similar harness was successfully developed for the 3-inch rifle (mounted on the wide 105-mm car-

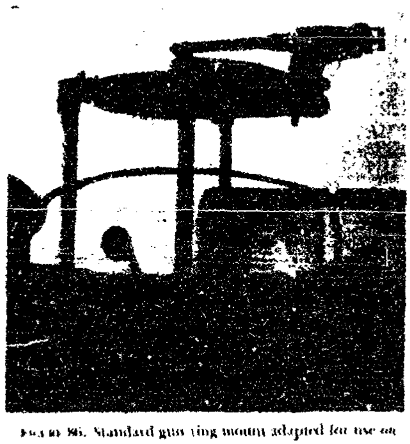


FIGURE 86. Standard gun ring mount adapted for use on DUKW.

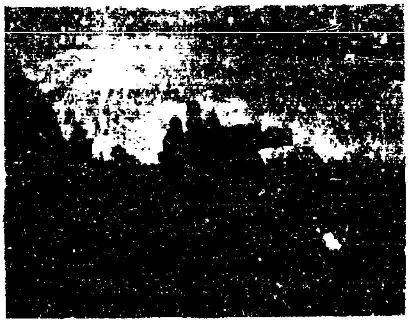


FIGURE 87. 105-mm howitzer can be handled easily by DUKW to fire on land.

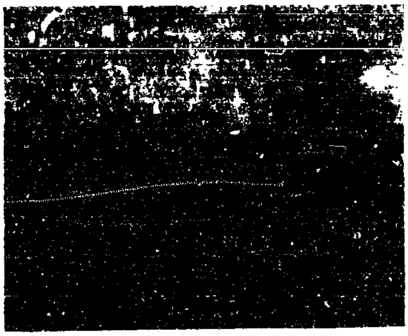


FIGURE 88. 105-mm howitzer on DUKW can also be fired at sea.

riage). This was undoubtedly the heaviest weapon to be fired from a DUKW. It was not used in combat.

It was found that the DUKW winch cable could be made to substitute for the harnesses for the 105-mm howitzer, the 25-pounder, and the 3-inch antitank rifle.

ROCKET LAUNCHERS

Early in 1943, exploratory studies and field tests indicated that the DUKW could be used effectively to carry launchers for the 4.5-inch beach barrage rocket. The cooperation of Division 3 of NDRC was obtained and an improved honeycomb-type, 120-rocket launcher was developed in collaboration with GMC Truck & Coach Division to replace the rail-type launcher then in use.[a]

Later, another type of launcher with a capacity of only eight rockets was tested for use on the rear deck of the DUKW. Lightly fastened to the vehicle, this launcher was found able to withstand single and ripple fire without difficulty and without harm to the DUKW.

5.7 DEMONSTRATIONS

5.7.1 Preliminary Demonstrations

The first pilot model of the DUKW, completed in 38 days, was displayed unofficially on June 2, 1942, and on June 12 it was demonstrated to a group of officers and civilians at the General Motors Corporation Proving Grounds at Milford, Michigan. Its operation on land and in water had a good reception, which was erroneously interpreted as an indication of early acceptance by the Armed Services. Four days later, on June 16, it was apparent that the DUKW could not be accepted early or, possibly, at all. The pilot model was driven to Fort Belvoir, Virginia, and demonstrated to Army officers, including representatives of the Engineer Board, whereupon the Chief, Corps of Engineers, indicated that there was no need for such a vehicle and recommended that its further development be halted. In spite of this conclusion, a third demonstration was held at Fort Story, Virginia, on June 23. A slightly more dramatic presentation was arranged, with a mock troop landing (Figure 89), but the reaction of military observers was again unsympathetic.

Thus, after 3 weeks, a series of small, inconclusive demonstrations had made a few friends for the DUKW but had failed to stir the imaginations of senior officers.

In the following weeks, other small-scale demonstrations and tests were conducted before official observers. On August 25 at Solomon's Island, Maryland, the reworked pilot model No. 1 was shown with the Ford ¼-ton amphibian and the Aqua-Cheetah of Hofheins; a similar comparison was made on September 16 at Camp Edwards, Massachusetts. Neither these nor other and unofficial displays resulted in the acceptance of the DUKW. The DUKW was either ignored or severely criticized for low water speed, difficulty of maneuvering, inability to get

[a] For a more detailed report, see Chapter 16, Section 16.1, on Project "Scorpion."

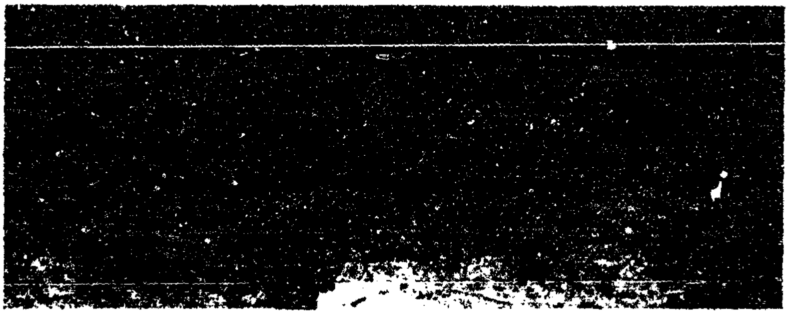


FIGURE 89. Mock troop landing staged at Fort Story, Virginia, to demonstrate tactical usefulness of DUKW and amphibious jeep (at right).

through surf, and unseaworthiness. There was a widespread conclusion that if the DUKW could perform a useful military function—which was doubtful—other vehicles could perform it better.

Even though the DUKW could clearly travel where no other single vehicle could operate, such as in deep water interrupted by sand bars (Figure 90), its operational advantages remained generally unappreciated. The DUKW idea had not caught on.

In the meantime, a most fortunate thing had happened. The Chief, Development Section, ASF, had received a directive from the Chief, ASF, to provide means for speeding the discharge of Lend-Lease cargoes at places like Basra, where ships were waiting 2 months before discharging into sailing lighters. Upon receipt of this directive, he was advised by the Chief of Division 12 of NDRC that 90 per cent of the world's beaches can be crossed by a wheeled vehicle with the right tire pressure, and forthwith, early in June 1942, he initiated a production order for 2,000 DUKWs before they had been tested or reported upon by the War Department. This order, received by General Motors Corporation on July 1, 1942, was presumably given, and certainly received, as an expedient—an emergency measure to employ something barely practical until a really useful logistical vehicle could be found. There was no assumption that such a production order meant acceptance of the DUKW as a vehicle acceptable to those military Services which could logically employ it on a large scale, and for the purposes outlined on page 13. On the contrary, it had become evident that none of the modest demonstrations conducted during the summer of 1942 had succeeded in satisfying the Services that the DUKW could make important and versatile contributions to logistics or tactics. OSRD,

FIGURE 90. Off Provincetown, Massachusetts, DUKW demonstrates its usefulness in operating in deep water interrupted by sand bars.

therefore, decided to stake the future of the DUKW on a massive and dramatic demonstration, in the roughest weather obtainable.

5.7.2 The Provincetown Demonstration

Once the need had become clear, OSRD personnel and representatives of the two contractors started plans for such a demonstration to be given early in December. After a survey of the East Coast, Provincetown, Massachusetts, was selected, since the backside of the hook was likely to have heavy surf and tide rips, while the shape of the incurving hook meant that on any given day any gradation of surf, from none to the maximum for that day, could be selected for training. Further, the water was generally too shallow for enemy submarines. It was determined that the program would include full-scale demonstrations of many actual applications of the DUKW and that the presentation would take advantage of rough winter weather rather than avoid it.

Accordingly, with the assistance of Army, Navy, and Maritime Commission officials who were personally interested in the program, preparations began on October 30. A special detachment of officers and men—the first "DUKW company"—was assigned to OSRD by the Commanding General, Engineer Amphibian Command, and started training to handle the DUKWs. Eight production models were requisitioned in addition to the four handmade pilot models. Special loading problems were conceived, and special equipment and methods were designed to solve them. Dummy cargo was made up by the Army and a Liberty ship was assigned to OSRD for the performance. OSRD personnel with great experience in navigating small craft, particularly in surf, provided special training to the drivers, crews, and officers.

For 30 days, this group developed and rehearsed its procedures in smooth and rough water, in surf, and in sand. It practiced mooring, loading and unloading, and handling every variety of cargo that could be obtained or simulated. The training equipment consisted of a 5-ton Lorraine crane, lashed amidships in an LCT from which dummy cargo was discharged into DUKWs lying off her weather side while the LCT steamed at 4 knots into quartering winter seas off Peaked Hill Bar on the back side of Cape Cod. It was hoped that these conditions were more boisterous than would be found on the lee side of a Liberty ship even in fairly heavy weather. This was found to be the case during the actual demonstration and, although the weather was moderately rough, no difficulty was encountered.

The actual demonstration was scheduled for December 6 and 7. In the early morning of December 2, however, the ability of the DUKW was tested in an unexpected dress rehearsal which became perhaps as important as any planned formal program. Shortly after midnight, a small Coast Guard patrol boat with her crew of seven men went aground on a sand bar about ¼ mile offshore on the northeast side of Cape Cod just inside Peaked Hill Bar. With the wind reaching a velocity of 60 mph, a hard, driving rain, and a good surf, the crew could not get ashore by swimming or by lifeboat or raft. Coast Guard personnel from three shore stations arrived with rescue equipment, but the high wind, the surf, and the strong current made it too risky to use a surf boat and the breeches buoy was impractical.

At the request of the local Coast Guard commander, two DUKWs were driven to the beach—about 15 miles from the demonstration headquarters—over roads and sand dunes. One DUKW was left on the beach for emergency. The other, driven and skippered by OSRD personnel and with two Coast Guardsmen as crew, went into the surf and out to the stranded vessel. Six minutes later, the DUKW returned with the seven crew members, dry shod, and carrying their personal gear.

The entire operation was described as uneventful (Figures 91 and 92).

Five hours later, at approximately 0630 hours, the rescue party returned to the spot to examine the vessel in daylight. The vessel, however, had disappeared and no trace of her was reported during the next week.

On the morning of December 6, the first of the two demonstration days at Provincetown, the official party of 86 officers from Washington, representing the Army, the Navy, the Coast Guard, the British Army, the Canadian Army, and the British Admiralty, arrived at Providence by train. They were met by buses and taken to Provincetown.

The weather had been encouragingly rough during the previous days but its sudden tendency to moderate during the night of December 5-6 spelled disaster for the demonstration. A courier with the heavy clothing and boots for the party was therefore sent from Provincetown to intercept the buses at Orleans and request the officers to change their

FIGURE 91. DUKW leaves beach on rescue mission off Provincetown, Massachusetts.

clothes en route so that the demonstration might begin without delay on their arrival, and before conditions "improved any further."

It will be seen later that these deliberate efforts at dramatization may have been too successful.

Under official observation for 2 days, the DUKWs proceeded to demonstrate their operational value. They repeatedly went through a moderate surf—the worst which could be located—and operated in a moderate sea with the wind at about 25 mph and waves ranging from 3 to 10 feet in height (Figure 93). Dummy cargo was taken on from the Liberty ship SS CARVER, which was standing about a mile and a quarter from the beach, and then carried to a dump established in sand dunes about a mile from the water. One DUKW was inadvertently loaded above rated capacity to about 8,000 pounds but seemed to manage just as well as the others, which averaged about 5,000 pounds of cargo. Unloading of small packages at the dump was done by hand, while improvised A-frames were used for large packages.

A special tactical demonstration was devoted to the landing of a 105-mm gun battery with four DUKWs. The battery was taken through a 4- to 5-foot surf (the highest available). The guns were unloaded with the A-frame, towed by the DUKWs across dunes not traversable by the standard prime mover, moved into battery, and there fired (Figures 94 to 96). Unloading time without rehearsal was about 2 minutes for each gun.

At the end of the demonstration, the DUKWs were turned over to the observers to drive and test in any manner they desired.

Following the demonstration and critique, the Assistant Chief of Staff, WDGS, G-3, announced his decision to send small consignments of DUKWs into four theaters of operations.

The demonstration, however, had been perhaps too successful. Because of the 30 days of rather drastic training with the LCT and because of the closest supervision during the demonstration, there had been no difficulty of any sort; thus the General Staff officers left Provincetown with the impression that the DUKW was a foolproof vehicle which could be

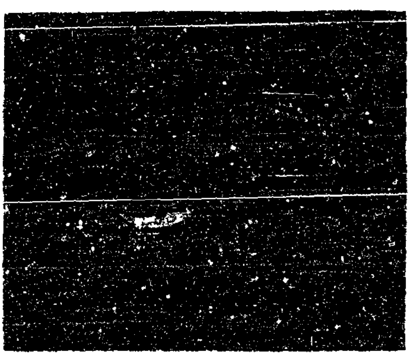


FIGURE 92. Coast Guard patrol boat with seven men aboard, aground on sand bar off Provincetown, Massachusetts.

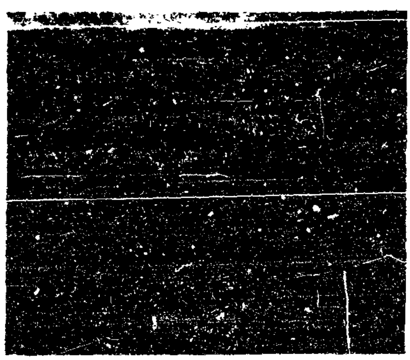


FIGURE 93. At official Provincetown demonstration, DUKW operates through moderate surf with waves ranging up to 6 feet in height.

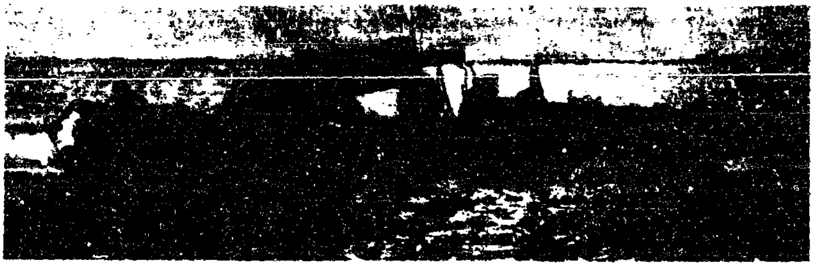


FIGURE 94. DUKW brings 105-mm howitzer ashore in Provincetown demonstration, December 1942.

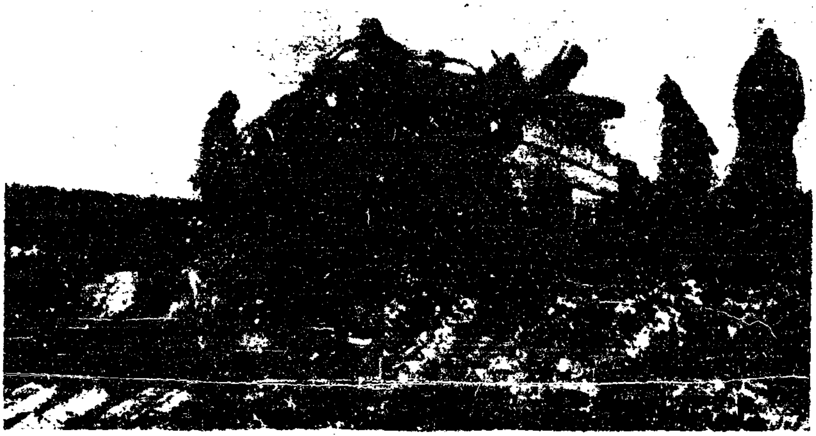


FIGURE 95. DUKW takes role of prime mover to haul howitzer over Provincetown sand dunes.

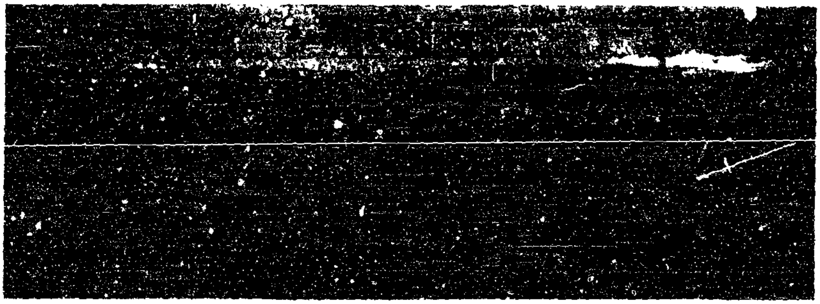
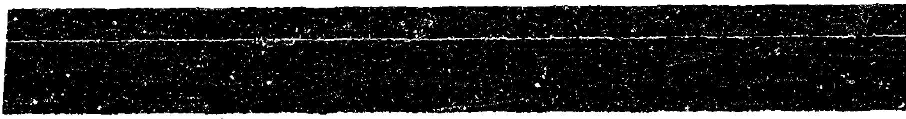


FIGURE 96. 105-mm howitzer unloaded from one DUKW with aid of A-frame on another is hauled into battery position.



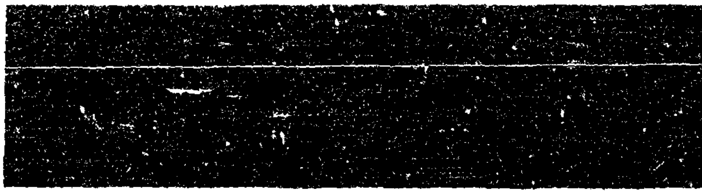


Figure 97. LCVs bringing cargo ashore in tests off Fort Story, Virginia.

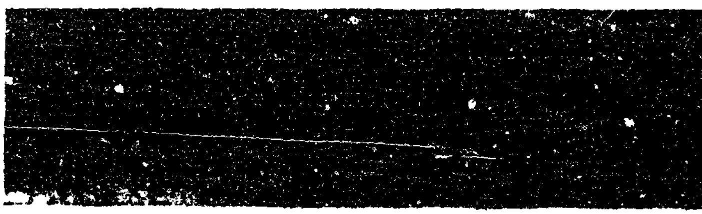


Figure 98. With LCV run as close as possible to beach, men wade into icy water to remove cargo.

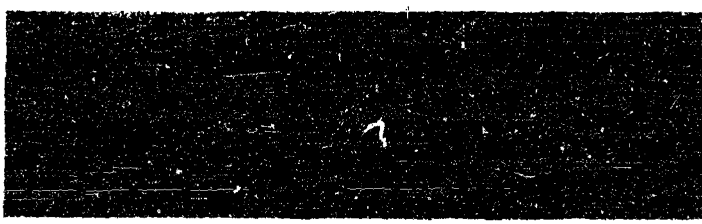


Figure 99. Men carry cargo from LCV to waiting bulldozer and sled.

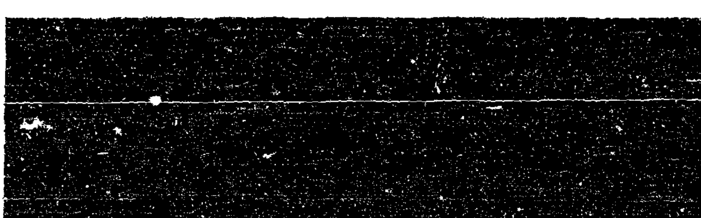


Figure 100. Last stage in LCV cargo landing routine. Men lift cargo on to standard land truck. (In Fort Story demonstration, LCVs landed only about 30 tons in 90 minutes.)

operated in heavy surf by any troops with very little training. This undoubtedly was a factor in the failure of the War Department to agree at once to the necessity for rigorous training of properly selected personnel, under competent military supervision.

5.7.5 The Fort Story Demonstration

Immediately after the Provincetown demonstration and because of the interest of officers of Amphibious Forces, Atlantic Fleet [AFAF] who had attended, the second major demonstration got under way at Fort Story, Virginia, culminating in a large-scale trial and competition with nonamphibious landing craft of comparable size. Again, the demonstration was preceded by rigorous training and rehearsal for a new set of inexperienced drivers. A method for unloading was developed by which cargo could be taken from a ship as fast as the ship's gear could discharge it over the side.

On January 3, 1943, in the presence of the Commander, AFAF, and his staff, ten DUKWs competed with ten LCVs in landing cargo from an AKA, with the DUKWs landing about 40 tons in 27 minutes and the LCVs about 30 tons in 90 minutes. Two days later in a repeat performance, the ten DUKWs landed 30 tons in 20 minutes, and the LCVs about 30 tons in 90 minutes, while the ten LCVs which were reinforced with two 50-foot Higgins Tank Lighters brought in about 20 tons in 60 minutes.

In these competitive runs, the LCVs ran as close as possible to the beach, where men had to wade into the water up to their hips to transfer the cargo through a small surf to the beach. Next a bulldozer dragged sled-loads of cargo up to dry sand where it could finally be loaded on a truck (Figures 97 to 100). During the trials, one LCV was flooded and stalled and had to be rescued by a DUKW; half of the LCVs had considerable difficulty in retracting from the beach after discharging their cargo; the 6x6 truck working with the LCVs had seven flat tires as a result of excessive tire deflation used to get across sand; and at the end, the commanding officer of the shore party reported that his men were freezing in the water and requested the aid of two DUKWs to get them back to quarters.

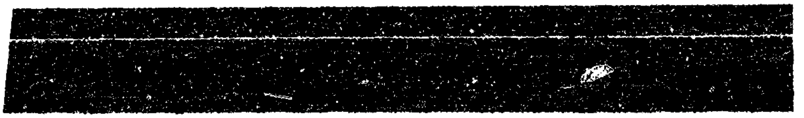
In contrast, the DUKWs took cargo directly from the ship, carried it across the beach, and unloaded it at the dump by means of an improvised "hog trough" chute (Figures 101 and 102). With this system, one DUKW with a driver and a crew of four disgorged 6,000 pounds of cargo in a minute and a half.

One serious accident occurred when a Navy driver overloaded his DUKW with 9,000 pounds of cargo, putting most of it in the rear end of the cargo space, and then lay alongside the *weather* side of the AKA for 45 minutes in a 4- to 5-foot sea. He likewise failed to rig his tarpaulin and waited until the very last to use the emergency hand pump. At the end of the 45 minutes, the motor stalled, the water gained fast, and the DUKW swamped in 60 feet of water.

Following the demonstration and competition, the Commander, AFAF, requested COMINCH for 2,000 DUKWs for the Sicilian invasion. Amphibious Section, COMINCH, turned down the request.

Later, the DUKWs were used to demonstrate both wet and dry ferrying of tanks, half-tracks, trucks, and jeeps. In a similar experiment in conjunction with an LCV, the landing vessel unloaded the tank on a sand bar and the tank was then brought ashore by two DUKWs. In other operations, observers wit-

FIGURE 101. In competitive demonstration at Fort Story, DUKW takes cargo from AKA standing offshore.



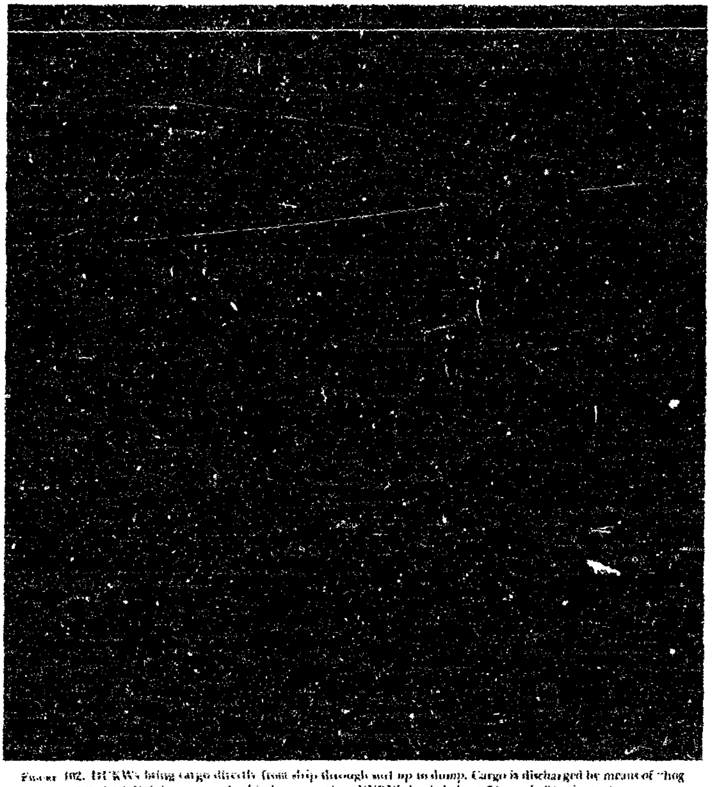


FIGURE 102. DUKWs bring cargo directly from ship through surf up to dump. Cargo is discharged by means of "hog trough" while DUKW is in motion. (In this demonstration, DUKWs landed about 50 tons in 20 minutes.)

nessed methods for loading DUKWs down the No. 2 hatch of Liberty ships (Figures 103 to 105), stowing them through the hatch of an LST, and suspending them from the davits of an AKA (Figure 106).

3.7.4 The Guadalcanal Demonstration

About 8 months after these demonstrations and after approximately 2,600 units had been produced, the relative value of the DUKW and the Water Buffalo was questioned by naval authorities on the Pacific Coast. To settle this problem, two standard production DUKWs, selected at random, and a pair of Water Buffalo pilot models, one 4x4 and one 6x6, were dispatched to Guadalcanal. The DUKWs were in the charge of OSRD personnel.

From September 23 to 26, 1944, the four vehicles were used to unload cargo from ships standing off

FIGURE 103. DUKW alongside Liberty ship with DUKW lifting sling being made fast.

FIGURE 104. Liberty ship jumbo boom lifting DUKW from water.

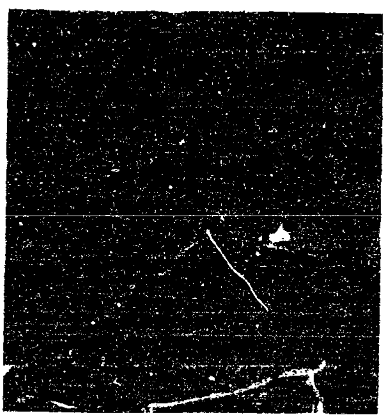


FIGURE 105. Stowage of DUKWs in Liberty ship in hold and on deck.

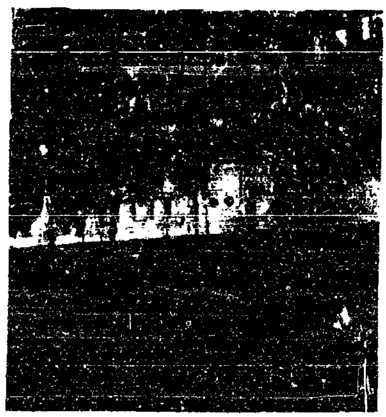


FIGURE 106. DUKW being lifted from water by AKA davits.

the beach at Guadalcanal. At the end of the first 2 days, each DUKW had carried almost as much cargo as both Buffaloes together and had made more trips than either Buffalo. During the next 2 days, with the 6x6 Buffalo laid up for repairs most of the time, each DUKW carried more than three times as much as the 4x4. Similar results were obtained between September 27 and 30 in comparable trials at Tulagi and in the Russells.

The cargo consisted mostly of ammunition, rations, and beer.

The Navy report on the demonstration was favorable to the DUKW but resulted in no Navy procurement.

3.7.5 The Funafuti Demonstration

In August 1943, CINCPAC was planning the assault on Tarawa and other coral atolls further west and requested OSRD personnel to determine, by test on Funafuti and by observations during the occupation of Nanomea, the extent—if any—to which DUKWs could climb out on coral reefs at various stages of the tide, on both the weather and lee sides of an atoll.

OSRD urged that this test should include the LVT in order that the basis might be laid for a standard operating procedure for a coordinated assault using each of the two vehicles to best advantage. This was rejected.

A consignment of 21 DUKWs was accordingly shipped from San Francisco to Funafuti, in the charge of OSRD personnel who serviced them en route. A detachment of Marine Corps personnel and a detachment of Army personnel trained in DUKWs at Fort Story were assigned to OSRD.

First, this composite force was trained in Funafuti lagoon by unloading a Liberty ship over lagoon coral at all tides. Then, after OSRD personnel had dived under the surf with bundles of dynamite sticks in sandbags to blast a ramp in the seaward lip of the coral reef as a precautionary measure, it was found that DUKWs could land through the surf on the weather side of a coral reef of the Funafuti type without any such aid. (See Figure 107.)

After 10 days of training, a group of 15 DUKWs with their crews was sent by LST to support the occupation of Nanomea. This figure 8-shaped atoll is a continuous reef. Its outer shelf is several hundred yards in width, full of potholes, and exposed about 18 inches at low tide. There is no entrance to either lagoon. On the weather side, the surf is heavy. On the lee side, the surf, deflected by each end of the atoll, strikes the coral shelf in two systems of waves

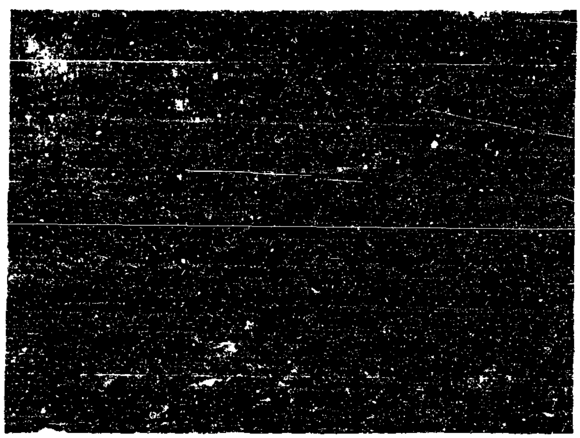


FIGURE 107. Using 30 pound tire pressure, DUKW negotiates coral reef in tests at Funafuti.

at right angles to each other and each at 45 degrees to the "beach." A northerly current of about 1 knot runs parallel to the long axis of the figure eight. Great fingers of coral, separated by gullies deep enough to swallow DUKWs, plunge to the depths at the line where the confused seas break.

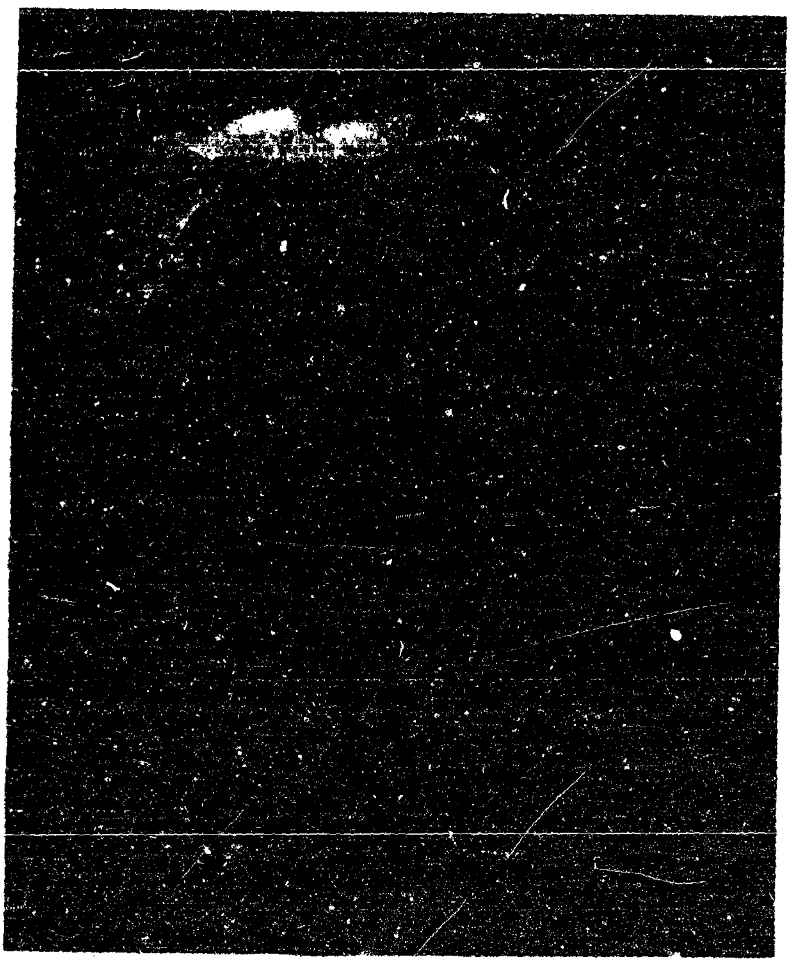
From the point of view of making a landing, this reef is reputedly the worst in the Central Pacific, and OSRD personnel found it far more difficult than that at Tarawa, which they had visited before the war.

Under these conditions, the Marine Corps drivers with 10 days of experience successfully landed on the Nanomea reef in the surf, being guided in a last-minute alteration of course by the difference in color between the dark water over the gullies and the pale green water over the coral fingers. Arriving at dusk, they discharged around the clock, taking combat stores from an LST lying offshore, running up a coral finger in the darkness by ranging in on two lanterns sited on the reef, and discharging directly to the dump. The stores were discharged by hog-trough over the side of the LST—a technique which was not successful with the jury rig available—and partly by entering and leaving the LST via its ramp.

One DUKW was damaged by surging seas on the LST ramp. One fell in a gully. Each was back in operation within a few days. The others operated without incident.

The operation made it clear that if relatively untrained crews under close supervision could operate DUKWs across Nanomea reef in all tides, by night and by day, then a well-trained DUKW company could do the same far more easily at Tarawa, first bringing in batteries of 105's and later supporting the assault with combat stores. A senior naval officer was present at the tests and concurred in the report which was sent at once to CINCPAC Headquarters. There the report was rejected. DUKWs were not used at Tarawa, either to land 105's for enfilading fire or in logistic support of the assault.[a]

[a] For an account of a successful use of DUKWs to support the assault against stronger opposition and over more jagged coral than at Tarawa, see the description in Chapter 1 of the operation against Peleliu.



Loaded with Marines and combat supplies, a U. S. Army DUKW is backed down the ramp of an LST. The scene: D Day at Iwo Jima.

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Chapter 4

THE DUKW: ITS APPLICATIONS

Summary

DUKWs[a] were first used operationally at Noumea in March 1943, a little less than 11 months after the Director of the Office of Scientific Research and Development [OSRD] had launched the project, and thereafter went through the war without a major design change, the basic design being considered satisfactory. The DUKW is one of few new weapons of its size with such a record. To eliminate those faults which, though minor, could cause a vehicle to fail in its missions, OSRD exerted the utmost pressure in getting necessary modifications into production. Some of the modifications requested by OSRD and approved by the War Department were, however, so long delayed in getting into production and so important to efficient operation of a DUKW fleet that, despite the shortage of time, materials, and men in forward areas, they were improvised in the field.

When the Army decided to start large-scale DUKW training, OSRD was already aware of many of the problems involved and was able to respond to the request for assistance in setting up schools, writing technical publications, improving maintenance, and developing special operating techniques. OSRD personnel were attached in a supervisory capacity to the early training schools in the United States and to retraining schools overseas.

The work of OSRD in the indoctrination of higher commands with the potentialities of the DUKW began with the sound film for the Joint New Weapons Committee of the Joint Chiefs of Staff, which outlined a part of the potential role of an Allied DUKW fleet. It was continued at a series of demonstrations for staff officers. In theaters of operations, cooperation of this sort was continued in conferences requested by the various theater commanders in the Mediterranean, European, and Pacific Theaters.

Training aids, including photographic and written material, were prepared for the Armed Services at their request. Assistance was given in drafting operating and other manuals, in theaters, special revised editions of operating manuals were prepared by OSRD and published locally.

Among the special logistical operating techniques developed by OSRD are stowage of various types of cargo in the DUKW, determination of the maximum permissible load for various conditions of sea and beach, DUKW mooring system, DUKW fleet control, operations with landing ships, evacuation of casualties, driving over coral, and underwater salvage. The most important tactical operating techniques include the use of DUKWs with the 105-mm howitzer, use with the 25-pounder, and use with the 4.5-inch beach barrage rocket. In addition, OSRD repeatedly urged the exploitation of the strategic surprise obtainable by landing DUKWs on a coast line fronted by an "impossible" surf or by "impassable" reefs and beaches.

Although one of the primary missions for which the DUKW was intended at the time of its design was to expedite the discharge of Lend-Lease cargoes in congested ports, OSRD worked with many officers and commands in finding new uses for the DUKW, including important tactical roles. In the end, OSRD, in close collaboration with theater forces, worked out a doctrine of a coordinated amphibious assault: DUKWs would be combined with LVTs to transport the assault troops, rockets, and 105 mm howitzers, the initial assault would be LVTs supported by rocket DUKWs, and subsequent covering fire would be provided by the 105's landed by DUKWs; the whole force would get sea-lift in ramp landing ships. Combat supplies in support of the assault would be brought in by DUKWs. This doctrine was first used at Arawe in December 1943, later at Kwajalein, and finally became standard doctrine throughout the Pacific.

OSRD made many attempts to insure that DUKW units overseas would be adequately supplied with spare parts, but these efforts were largely unsuccessful. Consequently, many DUKW companies relied on the cannibalization of other vehicles, especially DUKWs, and on the cooperation of Navy and Seabee machine shops for the fabrication of parts.

In order to simplify DUKW maintenance, the early overelaborate maintenance instructions were

[a] Readers of this chapter should first read the Summary and the Introduction at the beginning of Chapter 3, which apply also to Chapter 4.

revised. These maintenance instructions were eventually printed on dashboard plates.

In the following pages, the principal military applications of the DUKW are described, with particular reference to various technical successes and failures as they concerned the activities of OSRD.

Total production amounted to approximately 21,000 vehicles by August 1945, with a total of more than 27,000 authorized.

As a result of these close connections maintained with the DUKW not only throughout its developmental phase but also throughout its application, OSRD has arrived at certain conclusions and recommendations with respect to the problems encountered. Among these recommendations is one for further study on the possibilities of a larger, 15 ton, ¾-track amphibian which would supplement rather than replace the DUKW. Such an amphibian should be produced in both a combat model and a supply model.

4.1 MODIFICATIONS

As a result of continuous testing and observation in the United States and in theaters of operations, it was found that, although the basic design of the DUKW was sound, numerous minor changes were needed. OSRD therefore exerted the greatest possible pressure to eliminate those faults which, however relatively minor in nature, could nevertheless make the difference between the success or failure of an operation.

From the start of production until the end of the war, some 800 modifications were requested.[34] Most of them were initiated by the manufacturer to simplify shop assembly or to cope with a shortage of critical materials and were therefore not actually design changes. A limited number were requested by the Army. The others were requested by OSRD and were aimed at increasing the efficiency of the DUKW, expanding its versatility, and simplifying its maintenance. A representative list of some of the more important of these design changes called for by OSRD is given in Table 1, with the date on which each change was requested, the date on which it was introduced into production, and the approximate delay involved. About two dozen of these important modifications had been requested by OSRD by the end of 1943, and, although action on some of them was delayed, the DUKWs available for the invasion of Normandy in June 1944 were mechanically reliable, and 2,000 of them operated around the clock continuously for 90 days, with practically no time for maintenance. Another dozen changes of this type were requested by OSRD in 1944, none in 1945.

Table 2 gives a list of other changes which were requested by OSRD and approved by the Office of Chief of Ordnance, Detroit [OCOD], but which had not gone into production by the end of World War II.

It should be clearly understood that practically all of the changes concerned the amphibious components and not the automotive components. The latter had been incorporated into the conversion as well-proved, reliable units.

On the whole, this would seem to have been a rather modest modification program, attended by regrettable delays. The average time lag in getting the 26 representative, important modifications into production was more than 10 months (Table 2). These modifications did not in general involve critical materials or burdensome retooling problems. Some of the changes listed in Tables 1 and 2 were so vital to efficient DUKW operation that, despite the shortage of time, labor, and materials in the forward areas, they were made in the field. A few outstanding examples of the work performed in the field to correct such production deficiencies are as follows:

A-Frame Manufacture (see Table 1, MTER 2133). As mentioned in the section on accessory equipment in the previous chapter, production A-frames did not reach the theaters of operations in any considerable numbers: in fact, up to September 1944, there is no trace of a factory-made A-frame being used in the Mediterranean Theater, and it was necessary to improvise these frames out of any materials available in the forward areas.

Fuel Tank Drain Valve (see Table 1, MTER 2347). The large, packless fuel tank drain valve installed in fuel tanks having the sediment trap was installed in a bushing which was too lightly sweated into the tank. The vibration during water operation caused a dangerous fuel leak around the bushing; consequently, the bushing had to be brazed or soldered to the tank or the heavy drain valve had to be removed and a lighter petcock installed.

Sealing of Auxiliary Air Intake (see Table 1, MTER 2367). After 2 years of DUKW operations overseas, it was proved that this intake was not necessary to the cooling system; furthermore, since it was often inadvertently left partly open during water

TABLE 1. Important Design Changes in DUKW Production Models.

MTER* No.	Description of Change	Date Requested by OSRD	Date Put into Production	Time Lag (Months)
61	Improved exhaust manifold *(To reduce breakage in field)*	Jan. 1943	Aug. 1944	19
106 (a)	Improved oil filter inlet *(To reduce breakage in field)*	Oct. 1943	Feb. 1945	16
713	Improved brake shoe springs *(To reduce breakage in field)*	July 1943	Jan. 1944	6
2089	Coamings raised 1½ inches *(To increase effective freeboard)*	Jan. 1943	Mar. 1943	2
2133	Manufactured A-frame *(To permit lifting loads up to 5,000 lb)*	Dec. 1942	Sept. 1943	9
2141	Heavier sloping windshield with side wings *(To afford added protection in heavy surf)*	Feb. 1943	June 1943	4
2142	Central tire-inflation system *(To permit change in tire pressure while in motion, afloat, or ashore)*	July 1942	Dec. 1943	17
2155	Quick-action rudder control *(To simplify water steering)*	Jan. 1943	Apr. 1943	3
2164	Grease fittings on control lever bearings *(To reduce tendency of bearings to freeze)*	Jan. 1943	June 1943	5
2166	Two-speed marine propeller transfer case *(To improve reverse operation when afloat)*	Jan. 1943	Aug. 1943	7
2170	Bilge water hull drain valves *(To drain hull after water operation)*	Jan. 1943	June 1943	5
2193	Improved V strut bearing *(To increase life of bearing)*	Feb. 1943	June 1943	4
2235	Gould bilge pump system *(To provide more dependable bilge pump)*	July 1943	Dec. 1943	5
2317	Fuel tank water trap *(To facilitate removal of water from fuel system)*	Oct. 1943	Dec. 1944	14
2360	Locking flutes on rear wheel spacer studs *(To facilitate removal of wheels)*	Oct. 1943	Sept. 1944	11
2367	Omit auxiliary air intake *(To reduce probability of water getting on engine)*	Oct. 1943	Oct. 1944	12
2369	Stainless steel rudder cable *(To increase life of cable)*	Oct. 1943	Oct. 1944	12
2406	Reduced tarpaulin bow height *(To facilitate bow stowage in bow compartment)*	Oct. 1943	Mar. 1944	[illegible]
2426	Copper fuel lines *(To reduce clogging in fuel lines from rust)*	(Not recorded)	Oct. 1944	..

* Motor Transport Engineering Recommendations (GMC Symbols)

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TABLE 1. (*Continued*)

MTER* No.	Description of Change	Date Requested by OSRD	Date Put into Production	Time Lag (Months)
2511	Install tachometer (*To permit ready check on engine performance*)	Jan. 1943	June 1943	5
2527	Install hand signal light (*To facilitate visual communication and serve as trouble-spotlight*)	Oct. 1943	Oct. 1944	12
2561	Lucite headlights (*To reduce damage to headlights*)	Jan. 1944	Jan. 1945	12
2705	Raised tire-inflation standpipes (*To prevent standpipes jack-knifing over center*)	Jan. 1944	Jan. 1945	12
2717	Front brake hose protection (*To protect hose from wire, etc.*)	July 1943	Apr. 1945	21
2730	Front brake hose protection (*To reduce brake hose mortality and permit operation through water*)	Sept. 1943	June 1945	21
2731	Rear brake hose protection (*To reduce brake hose mortality and permit operation through water*)	Sept. 1943	May 1945	20
2768	Correct setting of front axle stops (*To reduce tendency to break shear pin or steering cable*)	Jan. 1944	Dec. 1944	11

* Motor Transport Engineering Recommendations (GMC Symbols).

operation, much damage was caused to the engine. The intake was consequently welded shut and caulked all around.

Steering Gear Adjustment to Prevent Shear Pin and Cable Failures (see Table 1, MTER 2768). Most failures were caused by faulty adjustment, which caused the rudder linkage at the stern to reach the end of its travel before the steering wheel rotation was stopped by the front axle turning stops. To prevent these failures, it was necessary to take four steps involving checks of the cable, rudder position, rudder-control lever, and front wheel turning angle.

Reinforcement of Coamings (see Table 2, MTER 2813). The cargo coamings, particularly the rear coaming, were found inadequate to withstand the strains of handling such cargo as bombs and heavy lumber. The upper edge of the rear coaming was therefore reinforced with angle or channel iron and the corners with strap, and the side coamings reinforced with strap. Any materials available were used, with many reinforcements improvised from barbed wire stakes.

Use of Rust Preventive Thin Film (see Table 2). Excessive corrosion due to salt water, especially on the hull and the external brake mechanisms, was a constant problem. The application of Rust Preventive Thin Film (AXS 673) reduced this corrosion to a minimum. It was used on all outside surfaces, including the brake shoes and backing plates of new vehicles.

Protective Grease on Brake Wheel Cylinders and Other Parts (see Table 2). Corrosion of the brake wheel cylinders, the three sealed ball bearings on the propeller drive shaft, and the winch drag brake-adjusting pin was minimized by the application of a mixture of one-third white lead and two-thirds water pump grease.

Propeller Guard (see Table 2). This guard was installed on DUKWs in the Pacific to minimize the chances of damaging the propeller and shaft during operations over coral and rock. The most satisfactory guard was made from 2½x¼-inch angle iron, but in many cases this material was not available. Some guards were made even with Japanese railroad iron,

TABLE 2. Important Changes Approved by OCOD but Not in Production by August 25, 1945.

MTER* No.	Description of Change	Date Requested by OSRD
2361	Improved front springs *(To reduce breakage)*	July 1943
	Move headlights 9 inches aft *(To reduce damage)*	Apr. 1944
2787	Rubber-covered brake wheel cylinders *(To increase life and eliminate need of complex grease protection)*	July 1944
	Use of Rust Preventive Thin Film (AXS 673) *(To reduce corrosion and increase vehicle life)*	July 1944
	Protective grease on brake wheel cylinders *(To reduce corrosion and increase life of parts)*	Oct. 1944
	Rustproof winch drag brake *(To increase life and reduce possibility of dropping heavy loads when A-framing)*	Mar. 1944
	Built-in hand bilge pump *(To provide more dependable means of eliminating bilge water when engine or mechanical pump system not operating)*	Nov. 1943
2812	Clutch on air compressor and materially increased oil capacity *(To decrease air compressor bearing failures)*	July 1944
	Propeller guard *(To reduce damage to propeller shafts and propeller, particularly in rough coral operation)*	July 1944
2813	Rear coaming reinforcement *(To reduce damage and insure maximum effective freeboard)*	Aug. 1944

* Motor Transport Engineering Recommendations (GMC Symbols).

Two important suggested changes which never received approval were still further increased hull freeboard and a continuous rope fender built all around the hull. Each was suggested in January 1943, and each was rejected on the ground that it would slow down production.

In addition, OSRD was sometimes able to arrange with the manufacturer for an advance shipment of kits for modifications about to go into production. This made it possible to bring up to date a group of DUKWs about to be shipped overseas. Thus, in early 1943, before they were shipped to the Southwest Pacific, some DUKWs were modified at Fort Ord, California, during the nights while they were being used for training by day; and in August 1943, the DUKWs shipped from San Francisco to Funafuti were partially modified and equipped with what spare parts could be obtained from the Stockton Ordnance Depot over a week end.

Even when the necessity for such field work is anticipated in the rear areas, the procurement of materials needed for making the modification and the time and labor required are major problems. Often, however, vehicles were shipped direct from the mainland to a combat area; in such cases it was necessary to decide whether to put the vehicle into an operation for which it was urgently needed, with the knowledge that it would require much additional maintenance work later, or to delay a much needed piece of equipment until it could be put into first-class operating condition. At Okinawa, for example, four amphibian truck companies arriving directly from the United States were not ready for operations until 2 weeks after the arrival of their DUKWs. However, two companies arriving from Oahu, where they had been given time and assistance in modifying their vehicles (Figures 1 and 2), were in full operation within 24 hours of landing.

In contemplating the amphibious conversion of a vehicle during wartime or any similar assignment, one might profitably consider the modifications described in this section and listed in detail elsewhere,[14] the delays encountered with them, and the amount of field work necessitated by such delays.

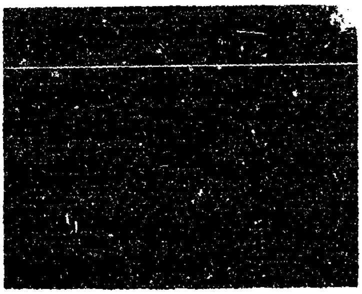

FIGURE 1. Preparing vehicle for combat at DUKW school on Oahu. DUKW brake wheel cylinders being coated with protective grease mixture.

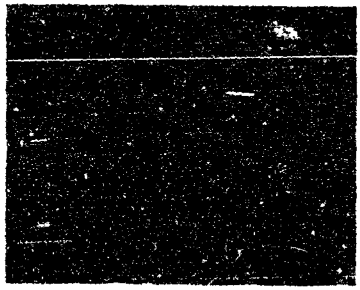

FIGURE 2. To minimize salt water corrosion, brake mechanisms and wheel backing plates are painted with zinc chromate and Rust Preventive Thin Film at Oahu DUKW school.

4.2 TRAINING AND INDOCTRINATION

During the early tests and demonstrations late in 1942, OSRD personnel were required to provide Army and Navy crews with a certain amount of training in the operation of DUKWs. Therefore, when the Army decided to start large-scale DUKW training, OSRD was already aware of many of the problems involved and was able to respond to the request for assistance in setting up schools, writing technical publications, and developing special techniques. This assistance was continued up to the end of the war.

4.2.1 DUKW Schools

Since the DUKW is a specialized weapon, specialized training is necessary for its efficient operation: the DUKW operator must be not only an expert truck driver, with the ability to handle a large and cumbersome land vehicle, but also a coxswain and seaman, experienced in handling a craft less maneuverable than the normal boat; in addition, he must be able to cope with the very difficult problem of operating between land and water, where considerable skill is necessary to negotiate heavy surf, coral, soft sand, and beach wreckage. Finally, he must have a thorough grounding in first echelon maintenance, which, because of the greater number of moving parts and their constant exposure to salt water, is more complex on the DUKW than on a land vehicle.

The first Army personnel to receive DUKW training were a small group from the Engineer Amphibian Command at Camp Edwards, Massachusetts. When the Transportation Corps [TC] school was started at Fort Story, Virginia, in January 1943, these men were used as instructors for several weeks until a sufficient number of TC officers and men were available to form a training cadre. At the request of the War Department, an OSRD adviser was permanently attached to the TC DUKW school until July 1943, when he was sent into active theaters to review and supervise DUKW operations and to organize refresher schools. After the first TC amphibian truck company was activated, training progressed until the facilities at Fort Story were no longer adequate. The school was moved in April 1943 to a site on the Isle of Palms, near Charleston, South Carolina, and continued there until late in the year, when it was moved to Camp Gordon Johnston, near Carabelle, Florida. OSRD, when consulted, advised strongly against this move, for reasons which will appear. The training of amphibian truck companies continued at the Florida location until the spring of 1945, when activation of companies in the United States ceased.

In addition to approximately 70 companies and several battalion headquarters trained at the TC school with the assistance and general supervision of OSRD personnel, other units were trained at a number of points in the United States, including Fort Pierce, Florida; Fort Ord, California; Camp Edwards, Massachusetts; and Camp San Luis Obispo, California. Several General Motors schools were also established for the training of DUKW mechanics.

Thus, early in the program, training was given principally in the United States, with the major site at Camp Gordon Johnston on the Florida Gulf Coast, where unfortunately the sand is firm and the water smooth. The training cargo was unrealistic and the cargo-handling equipment was deficient. Battle-tested operating procedures were not taught. The curriculum did not take heed of the fact that the percentage of 4's and 5's (War Department classifications) among the trainees was several times higher than the percentage of such groups in the Army as a whole.

Because of these and other shortcomings listed below, OSRD found it possible to obtain support in the European Theater of Operations and later in the Pacific for the creation of special schools in the theaters for the retraining of DUKW crews and officers under OSRD supervision.

1. Since Camp Gordon Johnston was not located near a port of embarkation, it was not feasible to train each DUKW crew on its own vehicle. Consequently, the crews were trained on school equipment, with the result that vehicle maintenance was not spurred by any pride of possession. In the overseas schools, on the other hand, it was easy to teach first and second echelon maintenance to DUKW crews who "owned" their vehicles.

2. Camp Gordon Johnston provided no opportunity to train DUKW drivers under conditions which were to become critical factors in actual assaults. There was no heavy surf like that at Tinian, no soft sand like the volcanic ash at Iwo Jima, no coral like that at Okinawa. In the theaters, training conditions were selected to resemble those which would be encountered when the unit went into operation.

3. Since the overseas training schools worked in close liaison with the higher headquarters which later employed the units, more was known about their future assignments and, consequently, training was given when necessary for such special techniques as transporting 105 mm howitzers and crossing coral reefs or swift rivers.

4. Overseas schools gave important assistance and advice to DUKW units on the procurement of special equipment and on the processing and modification of their vehicles. As mentioned above, there was much field work to be done on DUKWs after they had been shipped to the theaters of operations.

5. Camp Gordon Johnston was located in the deep South. Although the first amphibian truck companies were made up of white personnel with either truck driving or stevedoring backgrounds, by the fall of 1943 a change had been made to Negro enlisted men, though white officers were continued. There was a general lowering of the qualifications for DUKW operators; men with War Department classifications 4 and 5 were taken from such widely divergent units as Air Corps security battalions, smoke generator companies, and antiaircraft battalions and put into amphibian truck companies.

About half of these trainees were Negroes from the North. As was the case in other Southern camps, the morale of these men suffered from the necessity of conforming to the particular restrictions which they faced whenever they left camp. Such a situation would presumably have been less serious had the training camp been located in the North or on the West Coast. It actually was less serious, in fact, virtually nonexistent, in the overseas training camps, where the nearness of combat largely minimized many race prejudices. As a result of overseas training or retraining, Negro DUKW crews recovered their morale and acquitted themselves at least as well as white crews. In some cases they did better.

In Europe, they received high praise for their work on the Normandy beaches; at Iwo Jima they made more tonnage under fire than did white companies; and in the heavy surf at Tinian they were unsurpassed even by the best white Marine Corps units.

Nevertheless, there has been much discussion of the advisability of using such personnel as DUKW drivers. It has been held that operating the DUKW at sea, in high surf, over bad reefs, and on land, requires such a high degree of initiative and judgment that only men with special aptitudes and high personnel ratings should be trained as DUKW crews. It is true that companies with a high percentage of personnel of low I.Q. required a more thorough and a slower paced training, under closer leadership and supervision from their officers. But many of these Negro companies, retrained in theaters, have a performance record equal to that of the earlier companies composed of picked white men. In most cases, it was found that such a Negro company had officers of a very superior caliber, hardworking, enthusiastic about the DUKW, and sufficiently patient to cope with the multiplicity of problems inherent in the training of a group composed in large part of men in classifications 4 and 5.

If future DUKW drivers were selected with an I.Q.

at least equal to the average for the Army, the need for the special slower training and for special officers could be eliminated, perhaps resulting in a more efficient over-all use of the nation's manpower.

Nothing in combat experience has indicated to OSRD observers that, with comparable officers and training, Negroes do not make as satisfactory DUKW crews as white personnel of equal I.Q. In some respects, they are probably more satisfactory.

A particularly significant school was established at Fort Ord, California, at the request of the Commanding General, Second Amphibian (later Engineer Special) Brigade, where OSRD personnel set up and carried out an intensive training course during the 10 days prior to the sailing of the brigade. During these nights, the ordnance depot, under the supervision of GMC personnel, modified the 50 DUKWs and brought them up to date.

The first overseas DUKW school was set up in North Africa in April 1943 to train units for the coming Sicilian operation. One officer from this school continued his work later in Sicily and in Italy, training both American and British DUKW companies.

The Chief, Combined Operations (British), had shown an early appreciation of the potential value of the DUKW, and, at his request, OSRD personnel assisted in setting up a training program in May 1943. Their specific mission was to train a cadre of 50 officers and noncommissioned officers who would carry on subsequent DUKW training. The first and principal work of this instructor cadre was to be the training of a 100-vehicle DUKW company which was to be used in the Sicilian landings in early July.

The school was set up at Camp Dundonald, Scotland, but training had to be started before the arrival of the first DUKWs. Accordingly, some 2½-ton trucks were borrowed and used to give as much training as possible before the arrival of the first DUKWs. Actually, only two DUKWs arrived during the period set for cadre training, and these arrived only 2 days before the termination of this period. Since these vehicles were intended for combat in the very near future, additional difficulties were caused by the necessity of checking and servicing the vehicles upon their arrival.

OSRD personnel continued the work of training and indoctrination right up to the last moment, including some driver training given on the final trips out to the transports on which the DUKWs were to be loaded. Ship personnel were advised on the correct methods of handling DUKWs, including the carrying of a number of DUKWs in davits. The night before the departure of the convoy, a dozen A-frames, invaluable later in unloading artillery from DUKWs during the initial landings, were made under the supervision of OSRD personnel and delivered by the last DUKW to be loaded aboard. In view of all this pressure of time, much credit should be given to the DUKW crews, who performed well when they participated in the operation for which they had been trained. So great was their interest in their assignment that they took every available moment during the passage to the target to study written material on DUKW operations and maintenance.

Later, when the Chief, Combined Operations, had become Supreme Allied Commander, Southeast Asia Command [SEAC], he requested OSRD to assist in setting up a DUKW school in India at Juhu, near Bombay, in December 1943. At this school, several Royal Army Service Corps [RASC] companies were trained for subsequent operations on the Arakan coast of Burma. Personnel of these units had already driven trucks on the rugged terrain of Iraq and Iran, and they developed into excellent DUKW operators. An OSRD representative resided at this school for more than a month, and during that time introduced the DUKW mooring system, the transportation of artillery (principally the 25-pounder), the DUKW A-frame, the hog trough, the DUKW cargo pallet, and other techniques and equipment previously unfamiliar to British DUKW units in India. DUKW maintenance procedures were modified to conform with the British Army "Daily Task" maintenance system. In addition, several demonstrations were staged to indoctrinate the Commanding General, 33rd British Indian Corps, and other staff officers with DUKW capabilities.

In the meantime, the future possibilities of the DUKW in Pacific operations had become apparent to some American staff officers. At their request, OSRD personnel went to the Ellice Islands in September 1943 to train Marine Corps DUKW drivers for a special mission—the landing at Tarawa. On the basis of later operations, it appears that DUKWs would undoubtedly have been of prime value there in traversing the offshore reefs which proved to be such an obstacle to the conventional landing boats. Unfortunately, as noted below, the DUKW was not included in the Tarawa operation.

In early March 1944, amphibian truck companies

were arriving in England preparatory to the invasion of France. These companies were badly in need of training and other assistance in preparing for combat operations, and, accordingly, a TC DUKW school was started at Mumbles, South Wales, on the initiative of OSRD. The British Navy cooperated in making available a ship, complete with crew, for mooring and cargo-handling practice. This ship was used day and night in the intensive program necessary to train a large number of men in a short time. Fortunately, the Bristol Channel was rough during most of the training period, thus giving the students experience and confidence in a type of weather vastly different from the mild conditions at their school on the west coast of Florida.

In the meantime, another school for British Army DUKW companies was training units at Towyn in West Wales. At the request of Headquarters, Combined Operations, this school was visited on several occasions by an OSRD representative in order that British DUKW training could incorporate the latest operating and maintenance techniques that had been developed in other theaters. Also, at the request of Headquarters, 21st Army Group, visits for the indoctrination of the commands were made to British DUKW companies after their training and to the headquarters to which they were attached, at points where preinvasion exercises were being held.

In addition to this work, an OSRD representative was also responsible for giving last-minute training to six Negro companies which had arrived from the United States only 10 days before D-Day. These companies were being staged near the port of Cardiff before shipment for the French invasion. Several of their officers reported to the port command to which they were attached that almost the only DUKW training their men had received was at a DUKW school in the United States, where they had been taken for rides, about 18 men to a vehicle, with an instructor at the wheel of the DUKW.

One officer in the port command headquarters determined that these companies must receive more training, however brief, and requested aid from the OSRD man in charge of DUKW training at the American DUKW school in Wales. Since the work of this school was almost finished, attention was transferred immediately to the six companies. Fortunately, they were already assembled on the dunes near Porthcawl, on the Welsh coast, so the staging area was converted into a training area by the addition of a Dutch coasting vessel which was borrowed from the British Navy and anchored offshore. The weather was extremely rough and the surf considerable, making it possible to give valuable experience to Negro drivers who had never before been at the wheel of a DUKW. By virtue of round-the-clock training of the most intensive variety and the farsightedness and cooperation of the responsible TC officer, the men were prepared for their mission at least to some extent by the time they were loaded onto their LSTs for Normandy.

With the ever increasing demand for DUKWs in the Pacific and the complexity of the missions they were expected to perform there, the need for an "on-the-spot" school became apparent in the summer of 1944. The island of Oahu, with its many facilities and its position as Headquarters, Pacific Ocean Areas [POA], was selected for the location and, with the aid of OSRD, the school was set up by the Army Port and Service Command at Waimanalo on the east coast of the island, an excellent site incorporating coral reefs, heavy surf, and soft sand. A pier was constructed with three cargo hatches and booms to simulate shipside conditions. Close liaison was maintained with the ordnance office, and valuable cooperation was received in the preparation of vehicles for combat and in the rapid correction of mechanical deficiencies that developed during training. This school continued to operate up to the end of August 1945, providing training not only for amphibian truck companies and battalion headquarters but also for many other DUKW operating units from the Navy, Marine Corps, Army Air Force, Signal Corps, and Field Artillery (Figures 3 to 6).

The record of wartime DUKW training would suggest that if any future large-scale training of amphibian units should be given on the mainland, the program should be arranged so that the units are ready for combat when they are shipped. The military use of the DUKW provides outstanding support for the axiom that a piece of equipment, no matter how excellent, will not perform satisfactorily unless its operator is well trained. In every case in which DUKWs were issued to untrained personnel, the results were unfortunate.

4.2.2 Training Aids

Another phase of DUKW training and indoctrination in which OSRD played a part was in the production of photographic training aids. Under OSRD direction, both still and motion pictures were made

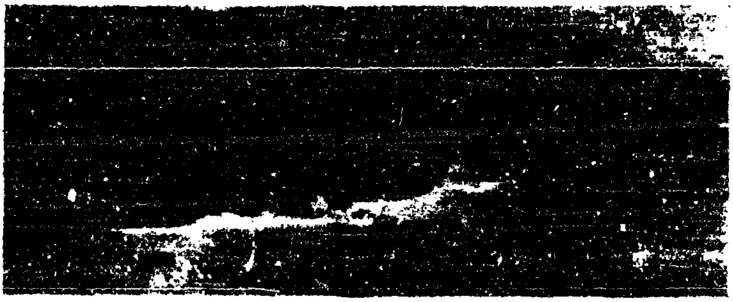

FIGURE 3. DUKW drivers in training at Waimanalo school, Oahu, transporting 105 mm howitzer. A-frame DUKW leads way to beach so A-frame can be set up by time howitzer arrives on shore.

of all the early tests and demonstrations in the United States, and by the beginning of 1943 there was sufficient material to make an album and a film. Copies of the album were distributed to interested General Staff Corps officers in Washington, to other officers elsewhere in the United States, and to the overseas headquarters of the theaters of operations. The film was made for the Joint Committee on New Weapons of the Joint Chiefs of Staff and was intended solely as a visual means of demonstrating the strategic potentialities of the DUKW to General Staff officers unable to witness actual field demonstrations. In addition, it proved to be a useful training aid in the orientation of driver students at the DUKW training schools.

In April 1943, OSRD was requested by the War Department to make another film[b] intended purely for training purposes. In addition to sequences showing various DUKW operations, such as mooring, winching, and A-framing, this film used scale models to illustrate some of the mechanical details.

Before this film was completed, the U. S. Army Signal Corps went to the DUKW school at Charleston, South Carolina, in May 1943 to make Film Bulletin No. 26 on the DUKW, to be entitled "DUKW, the

[b] This film was prepared by the Museum of Science and Industry, New York, N. Y., as subcontractor to Sparkman & Stephens, Inc., New York, N. Y., under OSRD contract OEMsr-154.

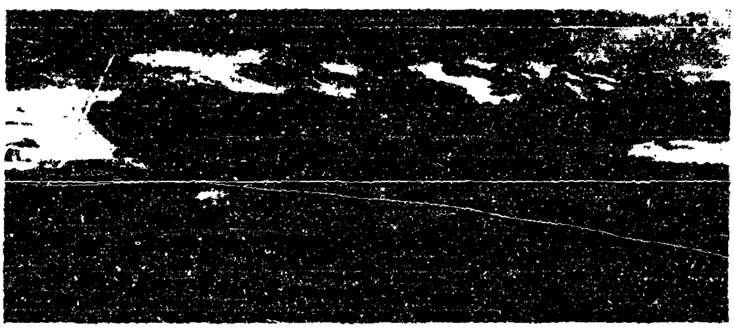

FIGURE 4. DUKW drivers training in coral driving techniques at Waimanalo. Lookout man is stationed on bow to select best route through bad reefs.

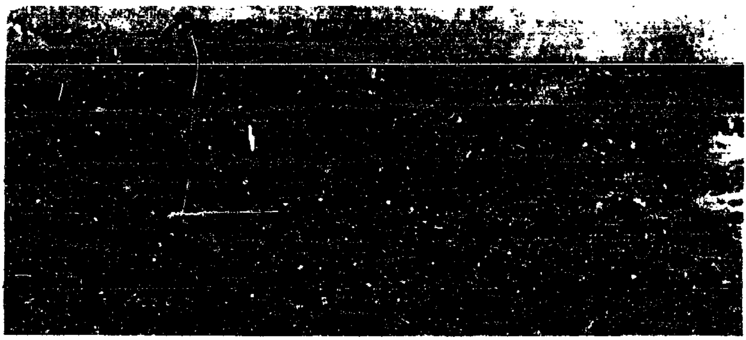

FIGURE 5. DUKW driver brings his vehicle out of coral reef on to boulder-studded beach during training course at Waimanalo. Instructor watches from beach as lookout on bow guides his driver.

Seagoing Truck." Although this was to be preliminary to a full length training film, an attempt was made to put as much training value as possible into it. An OSRD representative was requested first to advise on its production and subsequently to provide the accompanying commentary. No full length training film was made but this film bulletin was used at DUKW schools in the United States and overseas.

4.2.5 Publications

The first official publication on the DUKW was the Operator's Technical Manual, TM 9-802,[1] which was published in October 1942 and revised twice before the end of the war. This manual deals mainly with light and medium DUKW maintenance, and a copy is included in the auxiliary equipment issued on every DUKW. Several editions of a Service Parts Catalog for DUKWs, SNL G-501, were also issued,[3] a copy being included with every vehicle.

As soon as some of the early operating procedures were developed, OSRD produced a booklet of "driver's hints" in December 1942, with a revised edition[2] issued in the spring of 1943. In the absence of any other operating manual for the DUKW, the Ordnance Department waived regulations and early in 1943 authorized the manufacturer to place a copy of the December edition in the map compartment of each vehicle.

The urgent need for a more complete operator's manual was soon evident, however, and in March 1943, Field Manual 55-150, *Amphibian Truck Company*, was written for the Transportation Corps.[11] Unfortunately, this publication was not issued until November and it was several months thereafter before copies were distributed in the theaters. In the meantime, many new operating techniques had been developed, and many parts and controls on the DUKW itself had been changed. A new edition, therefore, was drafted in the spring of 1944, but again there was a regrettable delay, for it was not distrib-

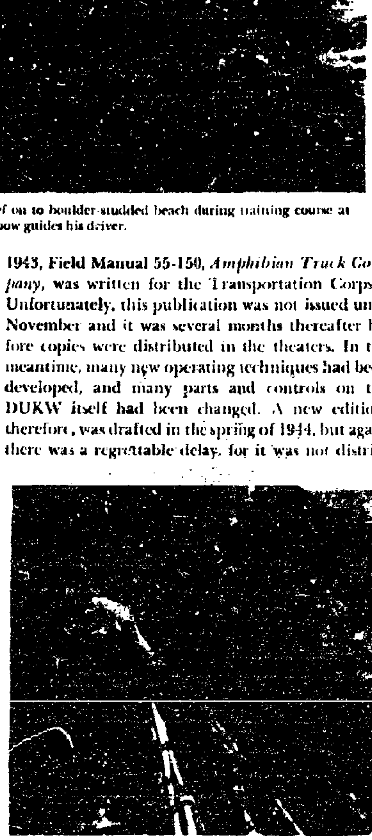

FIGURE 6. Cutaway model used at Oahu DUKW school to demonstrate many features not easily visible on ordinary production vehicle.

uted overseas until early 1945, when it, too, had become out of date.

Contrary to expectations, it was found that urgently needed publications could be produced overseas with far less delay than in Washington, even in spite of the scarcity of printing facilities. On Oahu, the manual *The DUKW—Its Operation and Uses*[25] was drafted by OSRD personnel for Headquarters, POA, in late September 1944; a month later, copies were being issued to DUKW companies as they commenced training. In March 1945, a reprint[28] was prepared at Manila in a matter of days for the benefit of companies in the Philippines. A month later, it was decided to bring the manual up to date with the latest doctrines and with information on the current modifications, and in less than a month this new edition[32] was in the field.

Besides these operator's manuals, numerous special instruction sheets prepared by OSRD were issued to the using Services in the field, generally in mimeographed form. These dealt with such items as maintenance, the mooring system, operations with LST's and LSMs, stowage in ship's davits, transportation of the 105-mm howitzer, use of the 4.5-inch beach barrage rocket, DUKW control, and coral operations. In addition, several technical bulletins summarizing the latest field modifications were issued by the Ordnance Department.

4.2.4 Special Techniques

As a result of its versatility, the DUKW was used by many arms of the Services on a variety of missions and under a variety of conditions. For such missions to be successful, careful study of the DUKW's limitations and a full realization of its potentialities were necessary, and practical standard operating procedures had to be developed. Even for its primary function of unloading ships, special techniques needed to be evolved to enable the DUKW to yield the most satisfactory results. The most important of these standard operating procedures, as developed by OSRD in cooperation with the Armed Services, are described below.

Logistical Techniques

Cargo Stowage in DUKWs. In order that DUKWs will be operated in a seaworthy condition and that their chassis will not be subjected to undue strain when driven over difficult terrain, the amount and positioning of cargo must be carefully determined. Such a determination must embrace the following factors: type and bulk of cargo, sea and surf conditions, beach conditions, distance of land run, and terrain conditions. The maximum safe weight of cargo for a DUKW can vary anywhere between 2 and 5 tons, depending upon these factors. The technique of DUKW loading should therefore be based on the advice of personnel experienced in DUKW operations. This is properly one of the functions of DUKW control described below.

DUKW Mooring System. The DUKW mooring system was developed in the early days of field testing during late 1942 in order to enable a DUKW to moor at high speed alongside a ship at a fixed point and to remain steadily at that point while receiving its load.

The system is based on the use of a single spring line leading astern to the deck of the ship. The power of the DUKW motor is used to hold the line taut after it is secured to the DUKW. The rudder is turned away from the ship, thereby holding the DUKW alongside and directly opposite the hatch to be unloaded.

The spring line is made of 3½- to 4½-inch rope about 100 feet long, with the forward end of the line carrying a mooring hook which is engaged in the DUKW mooring eye. A messenger line leading to the deck of the ship directly above the mooring position is fastened to the spring line at the hook end. In order to allow the driver sufficient time to secure the hook, the lines are rigged so that the spring line has about 10 feet of slack when it is not in use.

Originally, the system called for rigging a heavy guest warp along the side of the ship, with the DUKW spring lines attached to it. Field experience, however, showed that the guest warp is not necessary and consequently the spring lines are led directly from on deck (Figure 7). Except for this one simplification, the original technique has remained unchanged since its inception and all DUKW personnel received training in its use. Whenever possible, DUKW companies equipped themselves with lines in preparation for an operation, since it was found that, because of the unfamiliarity of Navy and stevedoring personnel with the system, it was preferable for the DUKW units to provide and rig the lines themselves. The rigging of all five hatches of a Liberty ship in this manner takes two men less than 10 minutes. Navy approval was eventually granted, the system was included in the U. S. Navy Transport Doctrine published in 1944 by

FIGURE 7. DUKW using approved high-speed mooring system, which involves single stern spring line and power of motor. Second DUKW is waiting to move into position as soon as first DUKW is fully loaded and cast off from spring line.

the Amphibious Forces, Pacific Fleet [AFPF], and recognition became more general in each succeeding operation. In addition to the advantages already described, it was found that this system gives the most satisfactory results in heavy seas and that it can also be used to advantage by other types of landing craft, such as LCVPs and LCMs.

DUKW Control. No matter how well-trained the drivers, the effectiveness of early DUKW operations was often greatly hampered by lack of understanding on the part of higher authorities. Improper use of the DUKWs usually resulted in wasting their potential carrying capacity, sometimes in causing maintenance to run unnecessarily high, and occasionally even in the total loss of the vehicles and their cargo. The questions of which missions DUKWs should perform and which they should not, how much cargo they could safely carry, how many DUKWs are needed to keep a hatch operating at maximum capacity, and many other similar problems called for operational control by personnel experienced in DUKW work.

Accordingly, OSRD developed and recommended a DUKW-control system which required the actual control work to be done by officers in the DUKW companies. Control points were set up at the beach, at the dump, on the ship, and in the parking area. Traffic was dispatched at a control center or command post through which had to pass all requests for DUKW dispatching. In small operations, this control center could be run by the commanding officer of the DUKW company, but in an operation involving several companies, it was recommended that DUKW control be under a battalion headquarters.

In all cases when a proper DUKW-control system was used, much higher tonnages of cargo were moved. Use of such a system meant that DUKWs would not be assigned to missions for which they are not suited and that their amphibious qualities would not be squandered in long land hauls. At the same time it provided higher authority with accurate information whenever necessary on DUKW performance and disposition.

Operations with Landing Ships. In the later stages of the war, landing ships, such as the LST and LSM, became increasingly important in transporting amphibians to the scene of their assault missions. While it would have been imprudent for the Navy to bring its larger transports close to enemy-defended beaches, it appeared that these more expendable landing ships could approach within a few miles, where LVTs and DUKWs with artillery, assault troops, and other high priority loads could be easily and speedily discharged into the sea.

As with many other techniques involving DUKWs, however, some difficulties were encountered, first, in convincing the using Services of the practicability of this operation and, second, in instituting the proper indoctrination. Even after this technique was adopted, several serious mistakes were made. When the pads recommended for the lower corners of the ramp curbs were not used on the LSTs and LSMs, DUKW hulls were often pierced; DUKWs were incorrectly loaded on stern first (Figure 8) and propeller guards and pintle hooks were consequently damaged on the ramp as the DUKWs drove out bow first; because of overloading, several DUKWs were sunk as they descended the steep ramp into a rough sea.

Frequent demonstrations were staged to prevent or minimize these accidents and literature was distributed as freely as possible. Operations with landing ships were incorporated by OSRD into DUKW training programs, not only for the benefit of DUKW crews but for Navy and Coast Guard personnel as well. Eventually, as in the case of the DUKW mooring system, the standard operating procedure was included in the Navy Transport Doctrine of AFPF (Figure 9).

Evacuation of Casualties. Special although quite

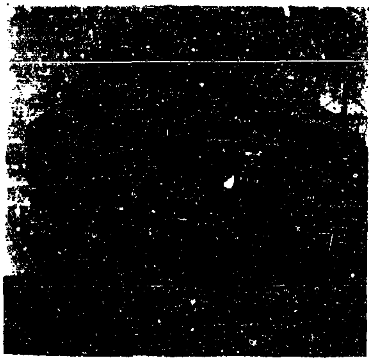

FIGURE 8. DUKW discharging from tank deck of LST into sea. This technique is incorrect. DUKW should be loaded on bow first so that it will back off, thus avoiding the possibility of damaging pintle hook, propeller guard, or propeller.

simple techniques were devised to use the DUKW for transporting wounded from field dressing station to hospital ship (Figures 10, 11, 12). With such a system, casualties do not have to be transferred at the water's edge from land vehicle to landing boat—a move that with bad surf or reef conditions, can be hazardous to a badly wounded man. Moreover, because of its extremely low center of gravity, the DUKW is far more stable than a boat and consequently does not subject casualties to such violent motion in rough water.

When LSTs are used for hospital work, DUKWs can drive up the ramp while the LST is afloat. The casualties can then be transferred to the sick bay directly from the tank deck.

Coral Driving. The development of a technique for driving over coral, one of the most important techniques used in DUKW operation, has been described in another chapter.[c]

Underwater Work. The DUKW proved useful in salvaging sunken supplies and equipment and in removing underwater obstacles from important channels. The DUKW air compressor will supply the air necessary for a diver, and an A-frame may be used to raise heavy loads to the surface. For shallow water, an adequate diving mask can be improvised from the standard service gas mask (with canister removed); for greater depths, however, a more elaborate helmet should generally be used. Weights for ballast may be secured to a belt which can be easily removed. If ex-

[c] See Chapter 5 in this volume.

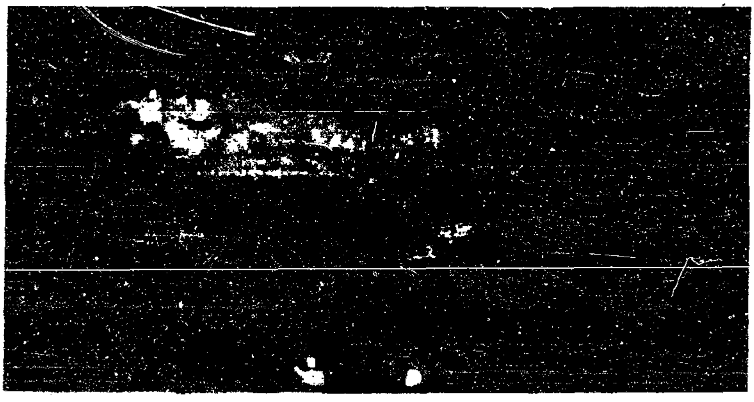

FIGURE 9. DUKW loaded with 105-mm shells, leaving LST off Noemfoor Island. Offshore reefs obliged landing ships to remain afloat while they were discharged by DUKWs which drove up ramps onto tank decks. Having backed off, DUKW is about to turn and head for shore. This demonstrates correct system of discharging. (Compare with Figure 8, which shows DUKW being driven out bow first.)

ceptionally heavy loads, such as a vehicle, are to be raised, additional flotation can be obtained by lashing several DUKWs together.

Tactical Techniques

Transportation of the 105-mm Howitzer. One of the most valuable tactical uses of the DUKW was the landing of the 105-mm howitzer in the early phases of an assault. By this means, batteries could provide supporting fire to infantry troops many hours, if not days, before it could be given by other means. This technique was used in many actual operations and was adopted by the British for the 25-pounder, the British field artillery counterpart of the 105. It was in Pacific island warfare that the most important results of this method were obtained. There the surprise element was capitalized to its fullest extent by landing the artillery at any point on a coast fronted for many miles by coral reefs.

Although the technique was developed and demonstrated under the supervision of OSRD in November 1942 and used in Sicily the following summer, a year passed before any interest in it was shown in the Pacific Theater. Then, at Milne Bay in New Guinea, a Marine Corps artillery battalion was trained in the technique, and a full dress demonstration[19] was staged under the supervision of OSRD personnel (Figures 13 and 14). This resulted in a decision by the Marine Corps to use the DUKW together with the LVT, so that in a typical landing the assault troops would be landed by LVTs while the DUKWs would bring in the artillery pieces and subsequently keep them supplied with ammunition.

Army amphibian truck companies, specially trained in the technique of handling howitzers, were there-

Figure 10. Demonstration of casualty evacuation by DUKW during demonstration for Surgeon General, POA, on Oahu. Bottom layer of six litters is complete. First litter of top layer is about to be passed up. Space is left for two attendants.

fore attached to Marine artillery units for the assault phase of the operation (Figures 15 and 16) and, in addition, Marine DUKW companies were activated for each of the six divisions. At the time of Japan's surrender, several Marine Corps amphibian tractor battalions were in the process of being converted into DUKW battalions.

According to this technique, whether the DUKWs are employed by the Marine Corps or the Army, it was recommended by OSRD that the vehicles serve with the field artillery battalions. At the port of embarkation, they are preloaded with the howitzers and approximately 45 rounds of ammunition. Some of them—usually one in five—are equipped with A frames for unloading the artillery after it has been landed. The normal gun crew accompanies its piece in the DUKW. When unloaded, the DUKW becomes

Figure 11. Passing up litters for top layer on DUKW. Handles of top litters can either be lashed with line or secured by plywood litter racks which are provided on all later DUKW models.

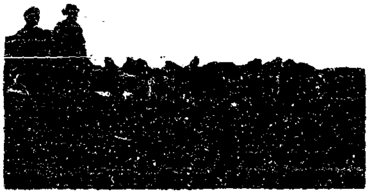

Figure 12. Top layer of six litters completes total of 12 litter patients and 2 attendants on DUKW. To protect patients from sun and spray, tarpaulin and bows can be installed.

FIGURE 13. During OSRD-initiated demonstration at Milne Bay, New Guinea, U. S. Marine Corps artillery is unloaded from one DUKW by another DUKW equipped with A-frame.

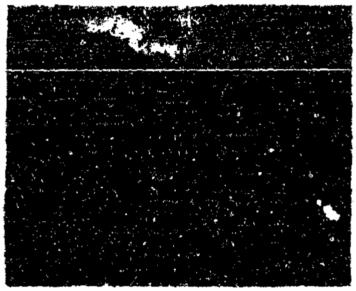

FIGURE 14. In OSRD initiated demonstration, Milne Bay, New Guinea, 105-mm howitzer is lowered to ground after being lifted from another DUKW which has moved away and is waiting to tow piece into battery position.

a temporary prime mover until the conventional prime mover can be landed. Observations under combat conditions showed that a well-trained team can rig the A-frame, unload the piece, and hitch it to the DUKW pintle hook in less than 75 seconds.

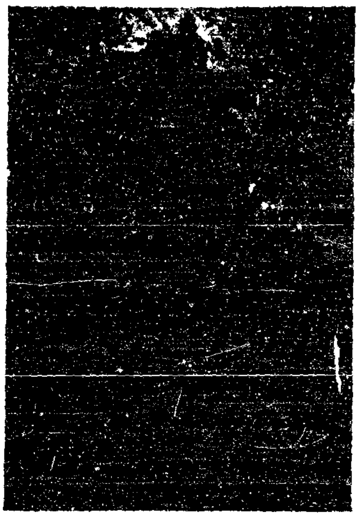

FIGURE 15. 105-mm howitzer with combat wheels stowed in DUKW, during demonstration on Oahu.

Rocket DUKW. Use of the DUKW as a source of amphibious beach barrage rocket fire power is described in a following chapter.[d] This use was first proposed to the Commanding General, Second Engineer Amphibian (later Special) Brigade [ESB], at Fort Ord, California, in February 1943, and equipment developed in collaboration with Division 3 was sent out with him to New Guinea. The equipment was later supplemented by four completely redesigned 120-tail, 4.5-inch rocket launcher installations equipped with motor-driven drum switches for controlled ripple fire. On arrival in New Guinea in September 1943, OSRD personnel found that this officer had not yet been permitted to use this weapon. Representations were made and, although it was impossible because of transportation difficulties to move the rocket DUKWs from Oro Bay where they then were to Milne Bay in time for a formal demonstration, they were nevertheless included in the demonstration by token. When the troops putting on the demonstration were activated as a force for the landing at Arawe on December 15, two of the four rocket DUKWs provided close supporting barrage fire, introducing this type of supporting fire to the Southwest Pacific [SOWESPAC]. These four vehicles continued to supply beach barrage fire until they were replaced by larger rocket landing craft.

Operations in "Impossible" Conditions. OSRD re-

[d] See Chapter 16 in this volume.

peatedly pointed out the part that DUKWs could play in achieving strategic surprise by landing at points where the presence of heavy surf, coral, or offshore sand bars had led the enemy to believe these coasts secure from attack. Since DUKWs with well-trained operators could safely negotiate a surf as high as 15 feet and could cross jagged barrier reefs and multiple sand bars, it was evident that the greater portion of enemy-held coast lines lay exposed to the possibility of amphibious assault.

This technique was never fully exploited, although it was used in part at some points on the coasts of Sicily and Normandy, at Tinian, and in the Ryukyus.

Evolution of Amphibious Assault Doctrine. Beginning with an amphibious vehicle designed primarily to expedite the discharge of Lend-Lease cargoes in congested harbors, OSRD worked with many officers and commands in finding new uses for the DUKW, including important tactical roles, which later became paramount. Finally, in closest collaboration with theater forces, OSRD worked out a doctrine of a coordinated amphibious assault which had these features:

1. It did not require sea-lift by vulnerable AKAs and APAs but used hard-to-torpedo LST's or other ramp landing ships.
2. It provided close fire support by rocket during the period immediately preceding and following the assault.
3. It provided for mounting the frontal assault in LVTs, carrying 75's and flame where necessary.
4. It provided supporting fire by 105's brought in by DUKW.
5. It was supported logistically in the assault phase by DUKWs.

This doctrine was first proposed in a series of conferences called by the Commander-in-Chief, Pacific Fleet [CINCPAC] at Pearl Harbor in August 1943, when it was presented as being applicable to the impending assault on Tarawa. It was rejected by AFPF. It was first demonstrated at Milne Bay in November 1943, where it was adopted by the Commander-in-Chief, SOWESPAC, who first used it at Arawe in December 1943. The use of DUKWs to transport 105's was adopted, probably independently, by the Seventh Division for the assault at Kwajalein. In the end, the general theory of this assault, modified by substituting larger rocket landing craft for the rocket DUKW, became standard throughout the Pacific. Various groups, presumably independently, worked out the same or a similar general doctrine.

4.3 MAINTENANCE

4.3.1 Spare Parts

The efforts of OSRD to insure that DUKW units overseas would be adequately supplied with spare parts were largely unsuccessful. These efforts began in late 1942, when a proposed list of parts to be shipped with every vehicle was submitted to OCOD and to the manufacturer. This list received joint approval, but it was not until almost a year later that any spare parts began to be issued with DUKWs, and even then they represented only a small proportion of the items on the original list. While this initial

Figure 16. Demonstration on Oahu to staff officers to show use of DUKWs in transporting 105-mm howitzers. When howitzer is lowered to ground, it is hooked to pintle hook on stern of DUKW, which becomes prime mover.

issue was useful in that it included such minor items as gaskets and spark plugs, it contained few of the major items peculiar—i.e., "parts peculiar"—to the DUKW.

In the meantime, satisfactory channels for procuring parts overseas were nonexistent. In fact, for some theaters such as the Mediterranean Theater of Operations [MTO] parts were never even shipped. In some other cases, parts were actually shipped to the theaters, but even then they tended to lose their identity in ordnance supply warehouses and dumps. OSRD personnel made frequent and strong recommendations to ordnance authorities in the United States that a study be made of a more satisfactory DUKW parts supply system. One suggested solution was to ship a 90-day supply of the major parts peculiar with every DUKW, a recommendation which was endorsed by every theater headquarters whenever proposed. Up to the end of the war, however, there were many instances when DUKWs were deadlined for weeks at a time for lack of parts.

This condition led to some very unorthodox methods of emergency parts procurement in the forward areas. Navy and Seabee personnel were most coöperative in providing the facilities of their machine shops for the fabrication of such marine parts as propellers, propeller shafts, bearings, and rudders. When such assistance was not available, land vehicles and Navy landing craft were cannibalized as much as possible; in some cases, parts for DUKWs were adapted from parts on British, Australian, and even Japanese trucks and landing craft. And, as a last resort, other DUKWs were cannibalized. It should be pointed out, however, that while the cannibalization of surveyed equipment can sometimes be justified on the grounds that it reduces demands on shipping, the cannibalization of serviceable equipment merely results in the gradual extinction of the operating fleet.

4.3.2 First and Second Echelon Maintenance

Early field experience soon proved that the somewhat overelaborate instructions originally issued for DUKW maintenance were not satisfactory. It was learned that better results could be obtained when a driver or mechanic was asked to work with a check list of only the essential maintenance duties to be performed, rather than with a long list including many unimportant duties.

Accordingly, simplified check lists were made up for daily driver maintenance, weekly maintenance, and monthly maintenance. These lists were distributed to companies undergoing training overseas and even to units that had been in operation for some time. Favorable reactions were received from the company officers and men.

Later, these maintenance instructions were approved by OCOD and printed on instruction plates which were installed on the dashboards of all DUKWs.

In order to reduce mechanical failures due to the corrosive action of salt water as much as possible, many external parts of the DUKW required coating with protective materials.

As pointed out in Section 4.1, this work should have been done in all cases on the mainland; actually, however, it was done in the field except in a few cases in which a responsible ordnance officer at a port of embarkation, convinced of the importance of this work, undertook to have it done before shipping vehicles to a theater of operations. Consequently, the waterproofing of corrodible parts became a vital function of DUKW units overseas, and drivers were trained whenever possible in these duties as a part of their normal first and second echelon work.

In cases in which OSRD was unable to indoctrinate DUKW units in this work, or in which time or materials were not available, serious corrosion resulted, with a consequent later increase in heavy maintenance and spare parts requirements, and a reduction in the operating life of the vehicle.

4.4 MILITARY USE

4.4.1 General

Approximately 90 per cent of all DUKW operations were conducted by DUKW companies. The great majority of these units were amphibian truck companies of the U. S. Army Transportation Corps.

The Table of Organization [T/O] strength of such a company was first set at 178 enlisted men and 6 officers, with a captain as commanding officer, but in May 1944 this was changed to 173 enlisted men and 7 officers. Each company was issued 50 DUKWs and was designed to operate on a round-the-clock basis, but in actual operations this organizational strength proved inadequate. It was found that for efficient round-the-clock operation, a theoretical

strength of 4.2 men per DUKW is necessary. This would give an amphibian truck company a T/O strength of 210 men; at least 15 of these men instead of the 11 as now prescribed should have mechanic's ratings.

With good operating conditions, it was expected that a company could haul cargo at such a rate that a 10,000-ton Liberty ship would be completely discharged in 72 hours. In practice, however, principally because of delays at the dumps and also because of enemy action and other factors beyond the control of the DUKW company, such a rate was very rarely maintained over a period of more than a few hours.

Beginning at Sicily in June 1943, some DUKW companies were organized informally around a battalion headquarters. Early in 1944, amphibian truck battalion headquarters were activated in the United States by the Transportation Corps and were invaluable in large operations, not only for handling a large proportion of the administrative work of the companies but also for acting as a higher headquarters to control the DUKW operation and to keep the operational and maintenance records. A battalion headquarters consisted of 12 enlisted men and 4 officers.

Marine DUKW units, known as U. S. Marine Corps DUKW companies, had an organization somewhat similar to that of the Army amphibian truck companies, but a larger number of mechanics was usually allowed, thus enabling maintenance rates in Marine companies to stay well within the prescribed figures.

The British Army DUKW companies were formed from RASC general transport companies. These units were composed of men with qualifications far higher than were required by the U. S. Army for a similar unit. Every man was selected for his driving and mechanical abilities, and the driver maintenance duties in these British companies were far more exacting. Each company had a strength of 470 men and was issued 120 DUKWs, together with 12 more representing a 10 per cent overstrength.

The remaining 10 per cent of DUKW operations not performed by DUKW companies were accounted for mostly by odd vehicles attached to divisions or operated by battalions with special missions to perform. Only a few DUKWs were operated by the Seabees or other Navy personnel.

It is well at this time to point out the disadvantages under which DUKWs operated when not in a DUKW company. In such cases, the operators usually had not received adequate training in either operation or maintenance of the vehicle. They were likely to encounter unusual difficulties in the procurement of spare parts and special tools. Also, it generally happened in such cases that the DUKWs were assigned to the unit without additional personnel and therefore the drivers were expected to maintain and operate their usual organizational vehicles in addition to their DUKWs. Consequently, not only the DUKWs but all the vehicles in the unit suffered from lack of proper maintenance.

The final argument against this method of operating usually became evident at the completion of the mission for which the DUKWs were procured, when the unit naturally lost all interest in them. They were left unattended in the parking area or turned in to some ordnance company, where they speedily deteriorated from salt water corrosion until they were no longer serviceable. Had an amphibian truck company or platoon been attached to the using unit for the performance of the mission, the using unit would have been relieved of the responsibilities of DUKW maintenance and similar problems for which they were not equipped. Then, at the termination of the mission, the DUKWs—still with their regular drivers and mechanics—could have reverted to their normal cargo-handling missions.

In concluding this general survey of DUKW operations, it is important to examine the attitude and morale of the men in the DUKW companies and to determine what they thought of their assignment and how their interest and morale should be rated. To OSRD observers, it appeared that the great majority of the men preferred working with DUKWs to any other work which they might have been given. Consequently, their interest was all that could be demanded and their morale remained high. This was particularly true once they were shipped overseas and were issued their own vehicles, in which they could take a personal pride. The system of issuing a vehicle to a driver and an assistant driver and of permitting no other men to operate their vehicle at any time should always be followed. It was far from unusual to see men painting and cleaning their DUKWs in time that was supposed to be their own.

The very fact that many companies were made up of men with no special qualifications, as already pointed out, made them all the more proud and interested when they found themselves identified

Figure 17. Initial landings at Sicily were made under smooth sea conditions.

with a weapon as important, versatile, and highly praised by the press as was the DUKW.

Below are described some of the principal amphibious operations in which DUKWs were used under OSRD supervision or cognizance. It will be noted that although the DUKW was originally intended exclusively for a supply function, many varied missions were developed for this vehicle, and in the end it came to serve as a tactical weapon almost as frequently as a logistical one.

4.4.2 Mediterranean Theater

The initial contingent of DUKWs to arrive in the Mediterranean was a group of 55 sent to Arzeu, Algeria, in March 1943. With them came 4 officers and 100 enlisted men from the Fort Story DUKW school. Even before the vehicles were tested, an order from headquarters, who apparently did not realize the potential importance of these men as a DUKW cadre, sent the four officers to a replacement depot, and the enlisted men were distributed about to various units. Only a handful of trained drivers stayed with the 55 DUKWs.

In the hands of completely unskilled personnel, who performed only a negligible amount of maintenance, the DUKWs soon fell into a deplorable condition. At this point, through the representations of OSRD to the War Department General Staff [WDGS], G-4, a qualified DUKW officer arrived from the United States and a course was set up to train completely new men to handle the vehicles. Since only a small number of DUKWs were in operation and many of these were being used in connection with amphibious problems, it was impossible to impart very much actual information to the trainees. Yet these same men were immediately used as a training cadre to teach other new men—while the original well-trained men from Fort Story were on other details.

In April, General George Patton visited Arzeu for a demonstration of the DUKWs and immediately requested many more for the forthcoming Sicilian invasion. This necessitated more drivers. With the extremely limited facilities and inferior training cadre, the quality of the products of the Arzeu school fell still lower.

At the end of May, the British Army in Africa was allocated a few DUKWs out of the original 55 and on these vehicles the American officer sent to Africa at OSRD urging trained two RASC general transport companies for DUKW operation.

Sicilian Invasion

In the Mediterranean, the DUKWs were first used operationally in the invasion of Sicily on July 10, 1943. The British on the east coast had about 300 vehicles, which were divided between two RASC

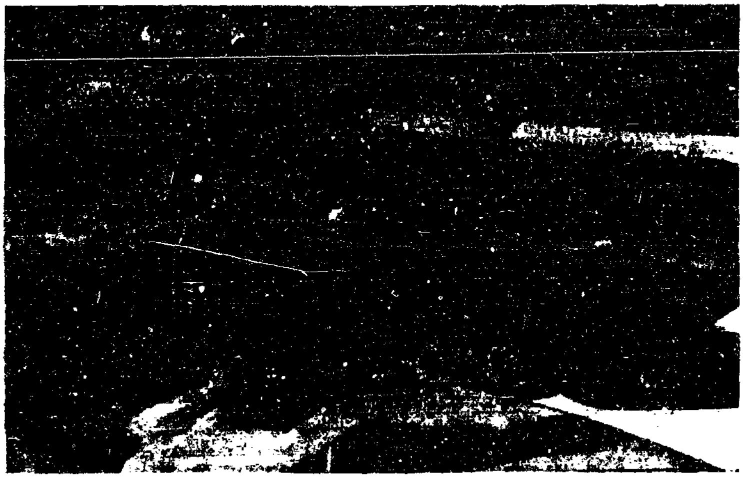

FIGURE 18. DUKWs used during Sicily landings to bring fuel directly from ship to fighter planes on newly captured airfield at Cape Pachino.

companies and a temporary group which left Scotland, after only brief DUKW training under direction of OSRD personnel, to come directly to the beaches of Sicily. The Americans used about 700 DUKWs, all handled by three Quartermaster trucking battalions and by three engineer combat regiments.

The original landing was conducted through surf so mild (Figure 17) that one DUKW managed to make a safe landing with a cargo of more than 7 tons. Although the bulk of the vehicles carried stores, a few landed 57- and 105-mm guns just after the assault. On the evening of D-Day, the weather turned bad and so much surf built up that for two full days it was impractical to use landing craft for cargoes. On these days, and on the third day, 90 per cent of all tonnage was DUKW-hauled.

Partly because of the enforced delay in bringing land trucks ashore but mostly because the proper use of DUKWs was not then understood, cargo was hauled directly from ships to dumps located 15 miles back from the beach. In some cases, gasoline was transported by DUKW from ships directly to planes on newly captured air strips (Figure 18). A substantial number of DUKWs were even appropriated by ranking officers to deliver supplies right up to front line troops and during one counterattack some 20 vehicles were captured by the Germans.

Practically no driver maintenance was performed during the first fortnight. This was due to lack of appreciation by responsible DUKW personnel of its importance and to the official policy that if the DUKWs "lasted for two weeks, they would have served their purpose," and no more would be expected of them. This lack had far-reaching effects from which the Mediterranean DUKW fleet never fully recovered.

In addition to their normal function, the DUKWs performed a great variety of tasks, ranging from the salvage of landing boats to taxiing high-ranking officers and unloading landing craft by A-frame (Figure 19). They were frequently used to tow land vehicles across soft sand. Some vehicles became so tied up in such "special work" that they did not revert to company control for 3 weeks, during which their amphibious capabilities were wasted.

The British DUKWs had no trouble in landing and the surf conditions in the British sector remained

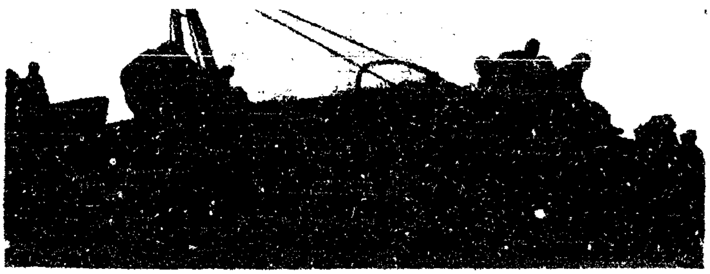

FIGURE 19. Unloading cargo at Sicily by means of DUKW A-frame. Since load is more than 3,000 pounds, counter weight is used on bow of DUKW to prevent its tipping. In case illustrated here, manpower is being used, but it is better to use 1,000 pounds of ammunition or other cargo, or to install brace under pintle hook on DUKW stern.

mild. There the main problems were the utter lack of cooperation from the Navy and the vast amount of waste motion in trying to find cargo to haul. The need for efficient centralized control became so apparent that the first DUKW-control system was evolved then and there. As with the American DUKWs, many unusual uses were found for the British vehicles, the most interesting of which was in salvaging material from sunken ships. Many important replacement supplies were raised at a time when they were otherwise unprocurable.

The following points became evident from the Sicilian operation.

1. The ignorance of the capabilities and limitations of the DUKWs exhibited by ranking officers of both Army and Navy caused a great loss both of tonnage hauled and of the vehicles themselves.

2. Control of DUKWs was a complicated problem, and one which greatly affected their efficiency. Naval cooperation was very poor, and DUKWs were too often used for unprofitable work.

3. Dumps were located too far inland, and DUKW efficiency was reduced by the resultant long road hauls.

4. Tables of Organization and Equipment were hopelessly inadequate to provide the maintenance needed for operation around the clock. Four men were found to be about the right number to handle each DUKW, but this number was virtually never available.

5. The over all potential of the DUKW fleet was not more than 25 per cent realized.

In spite of these points, however, the impressions made by DUKW performance were so favorable, particularly when compared to the alternative means of supply by LCM or LCVP plus human chain, that the Supreme Allied Commander, MTO, reported to the Chief of Staff that the DUKW had been invaluable, greatly facilitating the flow of supply over beaches, that on one beach it had been used as an assault craft, and that he could use many more.

End Runs. In the later stages of the Sicilian campaign, both the British on the east coast and the Americans along the north shore used DUKWs in commando raids or end runs, 105 mm batteries were landed and set up (Figure 20), and demolition equipment and men were carried. It began to be appreciated that the DUKWs were superior to landing craft in this work, where the speed of advance made it impossible to provide for adequate reconnaissance of landing conditions.

Messina Straits

On September 3, 1943, the British 8th Army invaded the mainland of Europe across the Straits of Messina. The current in the Straits is the second fastest in European waters, and naval authorities insisted that the DUKWs could not navigate in the narrowest section where the current speed is greatest. A wider place was chosen which required a run of 7 miles across water in a 2- to 3-knot current. At dawn of D Day, the entire force of 300 British DUKWs took to the water and swam across; not one failed to make the far shore. In fact, eventually more than 12,000 individual DUKW crossings were made without one failure.

The initial loads carried were extremely varied, including practically everything smaller than ¾-ton vehicles that an Army uses. The execution of the DUKW part of the invasion was perfect up to arrival on the far shore; reaching the dumps through narrow, congested streets was another matter, however, and the size of the DUKW was responsible for serious traffic jams. It was immediately apparent that special roads would have to be cut for use of DUKWs only, and this was done by bulldozer.

Soon after the invasion was started, experiments determined that DUKWs could easily cross the fastest currents in the Straits, but by that time the dumps were firmly established and no regular trips were made on the shorter run.

After the 8th Army moved north, the DUKWs followed up and worked the ports of Vibo Valentia and Sapri. Two platoons which temporarily stayed behind at the Straits made probably the longest overwater mass trip ever accomplished in DUKWs. In order to catch up with their headquarters, and because tires were a very critical item at that time, 72 DUKWs traveled from Messina to Sapri by water, a 2-day, 150-mile trip. All DUKWs arrived under their own power.

Salerno

In the meantime, two U. S. DUKW battalions made the Salerno landing against very strong enemy opposition. Because of the lack of cover, a great many DUKWs were struck by shell fragments and direct fire but these vehicles were cannibalized to put others back on the road.

The spare part situation up to this time was critical, for not more than 10 per cent of needed supplies were available. The fact that so many vehicles were kept running was a triumph of ingenuity and very hard work.

When Naples was captured in early October, the two U. S. DUKW battalions moved in and handled port work. An abortive attempt was made at this time to break in a Negro trucking battalion on DUKWs.

Under pressure to build up DUKW strength for the forthcoming Anzio landing, practically all vehicles were withdrawn from use by December. The next 6 weeks of frantic work by ordnance exposed the terrible toll taken by the lack of maintenance during the previous summer. As fast as DUKWs were "rebuilt" and put into a pool, other previously re-

FIGURE 20. Unloading 105-mm howitzer from DUKW by means of A-frame on another DUKW.

paired DUKWs would be found inoperative. In fact, of 20 such DUKWs taken to Salerno for embarkation, 16 were rejected by ordnance inspectors.

At this juncture, in response to a request from G-3 for a report on the amphibious logistics and tactics of Pacific DUKW operations, OSRD personnel arrived at Headquarters, Allied Forces [AFHQ], Algiers. Targets of vehicle availability and of tonnage capacity were set.

End Run. In the last week of December, a number of DUKWs participated in an end run around the mouth of the Garigliano River. This was quite successful until the last trip back, when many vehicles became mired in the shallow mud in the center of the river. Even after prodigious labor to free them, several were permanently lost. While it was well-known before that the DUKW was poor in mud, this was the first operational loss resulting from it in the MTO, and spurred studies to improve DUKW performance in mud (see Chapter 3, Section 3.6.1).

Anzio

The Anzio landing, which continued in full force for 4 months, started off with a complete showdown on the results of poor maintenance of the U. S. DUKWs. Working side by side with two U. S. DUKW battalions was one RASC company which used DUKWs of the same age and mileage; yet on D+1, the British deadline was only 11 per cent, whereas the U. S. deadline stood at 55 per cent. It took the services of six ordnance companies, either in whole or in part, to improve this condition.

The initial assault at Anzio on January 22, 1944, had been quite normal: guns, ammunition, rations,

Figure 21. DUKWs landing at Anzio. The beach exit, specially paved with landing mat sections, is rarely required by DUKW unless beach is muddy.

and fuel were carried (Figure 21). In the succeeding months, every and any type of cargo weighing up to 4 tons was brought ashore in DUKWs. By this time the Germans were fully aware of the importance of DUKWs to the Allies and made special efforts to disable them. Their favorite method involved the use of antipersonnel bombs and shells, which were all too effective (Figure 22). One vehicle, however, remained in service after having received more than 200 holes in its hull.

Up to this time it can be said that the full potentialities of DUKWs had never been utilized. Control was improving, but lack of cooperation from the Navy remained a large factor in producing poor tonnage reports. In the spring of 1944, following representations by OSRD in Washington, a senior officer from the Army Service Forces [ASF] visited the MTO and made a study of amphibious work. His recommendations included the activation of TC amphibian truck companies which, with proper training, could produce the tonnages that were theoretically possible.

On this basis, four TC amphibian truck companies

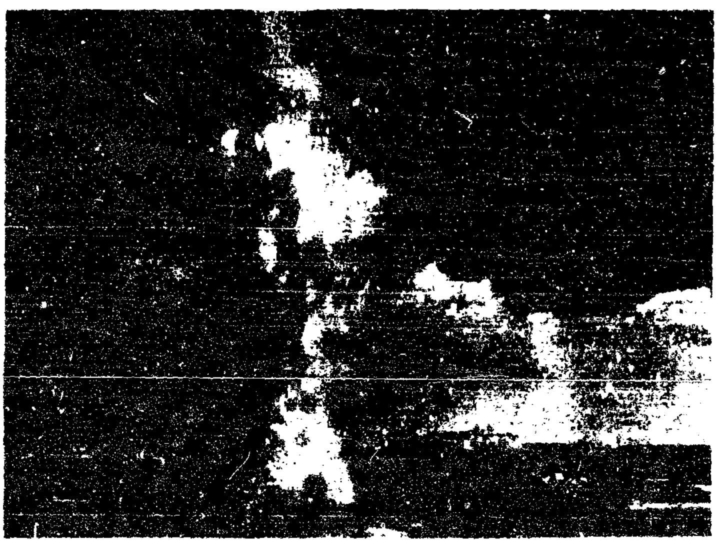

Figure 22. Near miss on DUKWs ferrying supplies ashore at Anzio beachhead.

FIGURE 23. DUKWs loaded with assault troops discharging from LCTs under easy conditions in southern France.

were formed under the control of the 147th Quartermaster Battalion Headquarters. It should be explained that each company of two battalions formed earlier had had a T/O of 110 men, but that a paper battalion of 120 men had been divided between these two so that each company actually had more than 170 enlisted men. The 147th therefore had about the same number of men per company but far better maintenance facilities. On top of this, special authorization was received for additional equipment and the companies normally handled all repairs through third echelon.

Southern France

The invasion of southern France began on August 15, 1944 (Figure 23). All DUKWs were handled by three battalions, since it had been found impractical to have small numbers in the hands of Engineer Corps regiments. Each battalion landed 100 extra "old" DUKWs. Of their basic 200 Table of Equipment [T/E] vehicles, 20 were also "old" and the remainder were just off the assembly line and equipped with the new controllable central tire-inflation system. A considerable number of 40-mm, 57-mm, and 105-mm guns were landed, the latter so rigged that they could fire from inside the DUKW. One "suicide" DUKW was also included, prepared to blow itself up in order to breach a concrete sea wall in case other means failed.

One-half of all T/E DUKWs were equipped with locally manufactured A-frames and raisers because it was felt that this was necessary for the rapid unloading of artillery pieces. After the assault phase, 25 per cent, or one company, of these DUKWs were detailed to work dumps in place of cranes, of which very few were available. Thus only three companies actually hauled cargo, while the fourth worked A-frames in loading and unloading all types of vehicles (Figure 24).

With the three companies hauling cargo, 5,000 tons per day, or 33 tons per DUKW per day, were easily handled when ships were available. Again, Navy cooperation was generally lacking and about 30 per cent of all DUKW hours were unproductive.

As the main Army moved north, the DUKWs went into Marseilles and worked the east end of the port. This was not a very profitable venture and for much the same reason as was found at Messina: the DUKWs tied up traffic throughout the city and the shore-to-dump time became fantastically high. Unfortunately, it was impossible to cut special DUKW routes through Marseilles.

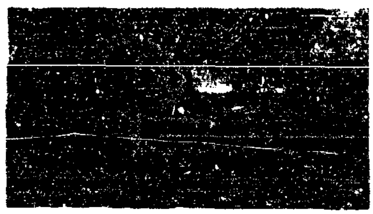

FIGURE 24. DUKW A-frame used to unload Signal Corps wire from causeway in southern France.

Considerable salvage work on sunken vehicles and supplies was performed after the initial assault on the southern coast and later at Marseilles, but otherwise the work performed was routine.

The main features of DUKW operation at this period were: (1) the outstanding success of an integrated DUKW battalion in handling large amounts of cargo day in and day out; (2) the full-scale use of radio, which in a large measure made this integration possible; and (3) the considerable use of DUKW A-frames to substitute for unavailable cranes.

When the Army reached Epinal, it was felt that DUKWs should be available for possible river crossings, and the 147th came to Lyon to practice in the Rhône River. It was immediately apparent that the swift current and the uncertain bottom together made for conditions completely different from any which had been met before. At first, a cable crossing rig seemed to offer the only feasible solution, and all drivers were trained to use it. However, as more experiments were made and greater experience was gained, it became clear that free-ferrying was superior, in spite of the fact that drivers required very intensive training in this method.

The two 7th Army DUKW battalions were trained in this procedure preparatory to a proposed crossing of the Rhine. Two DUKWs actually applied it earlier in connection with a commando raid on December 28 and thus became the first Allied vehicles to cross the Rhine. This crossing was made at a point 9 miles north of Strasbourg.

Certain other experiments were also conducted at this time, particularly on the use of DUKWs in mud and on the firing of 3-inch antitank guns without special harnesses. Mud had always been responsible for the major operational failures of the DUKW, and methods were sought to reduce them. A fairly elaborate technique was evolved, and with a metal "ladder" to facilitate climbing muddy banks, it was thought that a skilled driver could negotiate reasonably bad terrain. The 3-inch antitank gun, mounted on the wide 105-mm carriage, is undoubtedly the heaviest piece fired from a DUKW. With the gun held in place by the winch cable and with no special rig other than wheel blocks, its use on the DUKW was found to be entirely feasible. During the first few rounds, the gun appeared to be more accurate in a DUKW than when in normal ground position — a phenomenon due to the absence of settling of its wheels.

4.4.3 European Theater

Normandy Coast

The ability of the DUKW to move stores across stormy beaches was deliberately exploited for the first time by the planners of the Normandy invasion. The German General Staff, according to later reports by the Commander-in-Chief, Allied Expeditionary Forces, felt that the storm-lashed Normandy beaches provided no means adequate to support an offensive by several million men. Their judgment coincided with that expressed to Division 12 in 1942 by representatives of the Allied High Command, who concluded that the Allied forces would have to use captured ports. It appeared logical, therefore, that the Germans should base their strategy on a stubborn defense and subsequent demolition of Cherbourg and the other ports. The DUKW fleet was an essential element in the strategic surprise of the enemy and continued to support the advance to the Rhine in all weather. Representatives of Supreme Headquarters, Allied Expeditionary Forces, later advised the Chief of Division 12 of NDRC that between June 6 and September 1 the Allied DUKW fleet had carried across the beaches approximately 40 per cent of the total stores landed.

In the invasion of Normandy, the first DUKWs landed on D-Day and by D + 60 approximately 2,000 vehicles were operating on the Normandy coast. Of these, about 800 were operated by the British, serving under the British 2nd Army on its sector of the coast. The others were operated by amphibian truck companies of the U. S. Army Transportation Corps. Six of these companies, manned by white enlisted men, had been in England for more than 6 months before D-Day. They were attached to the 1st, 5th, and 6th ESB's and were trained under the cognizance of General Daniel Noce, whose EAC Command at Camp Edwards, Massachusetts, had supplied the detachment for the Provincetown demonstration in December 1943. Fully cognizant of DUKW problems, General Noce met with OSRD personnel in London in January 1944 to review the various recent developments in other theaters, and arranged that these six companies, while stationed on the coasts of Devon and Wales, should be given ample time to incorporate these new developments in their training.

Other companies, manned by Negroes, did not begin arriving until late in March 1944. They were not in condition to meet the tonnage figures guaran-

reed to the Staff Planners. It was necessary to create facilities, retrain the men, and prepare their equipment. This was done under OSRD supervision.

The 1st ESB landed on Utah Beach, the 5th and 6th on Omaha Beach (Figure 25). Their DUKWs were loaded with high priority engineer equipment and ammunition. Routes through the underwater obstacles and the beach mine fields were being cleared and marked to a limited extent, but the beaches were under heavy enemy fire and a number of DUKWs were hit by mortar fire. Some were damaged by land mines, but it is of interest to note that while the driver of a land truck is generally killed or at least suffers broken legs if his vehicle detonates a mine, a DUKW driver is rarely hurt, the front wheels and engine compartment apparently absorbing the full shock of the explosion.

The first of the Negro companies arrived on the beach in LSTs and LCTs on D + 3; others arrived later and were attached to port commands.

In order to minimize the DUKW land runs, transfer points were set up in the dunes close to the beaches (Figure 26). Some of the transfer rigs were built of pipe frameworks with winches installed; others consisted of a high lift truck together with a special overhead lifting finger mounted on either a land truck or a wood platform. Later, cranes arrived and to some extent replaced these transfer rigs.

While the firm sand of the beaches was ideal for the DUKWs, other operating conditions were not so favorable. In the first place, the ships widely used in the early phases were the relatively expendable North Sea two- or three-hatch coasters with an average 700-ton capacity. These ships were important because their small size made them difficult targets and because their shoal draft enabled them to anchor close to shore, though they had a very violent roll in the generally rough English Channel waters. In comparison with the usual large freighters, these coasters were not suited to efficient DUKW operations. Many of them had heavy guardrails along each side, and these caused much damage to DUKW hulls and headlights.

Another source of difficulty in the first few days was the great amount of tactical smoke which was generated among the ships. This made it so difficult for DUKWs and other landing craft to find their way between ships and beaches that it was very soon discontinued as being more trouble than it was worth.

Sea conditions were bad most of the time. The prevailing wind was from the northwest, making it particularly bad at Omaha Beach, which was open to the north. The surf ran high at times, and tides occasionally ran as fast as 3 knots. Further trouble was caused by the great amount of wreckage and spilled cargo close to the shore. There was a high mortality in DUKW propellers and rudders until drivers were instructed to disengage their propellers and coast through the most congested water areas.

The installation of the offshore breakwater of blockships at Arromanches, in the British sector, was of great value to British DUKW operations. From then on, these DUKWs were able to operate in relatively smooth water, and their maintenance troubles were considerably lessened. A similar breakwater off the American beaches had been almost completely destroyed on June 23 in the worst summer storm for 20 years. This meant that the U. S. Army DUKWs were obliged to continue operations in open sea conditions, which caused higher deadline rates.

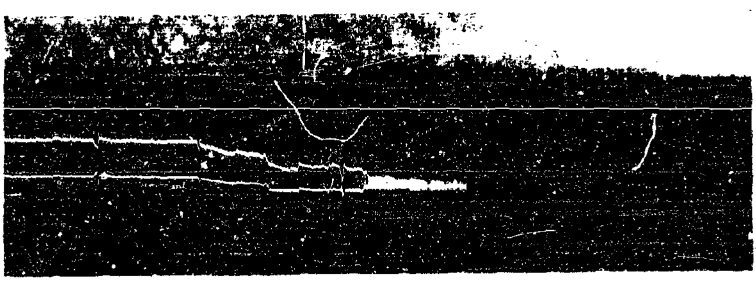

FIGURE 25. Initial landing of DUKW fleet on Utah Beach. The water was rougher off Omaha Beach

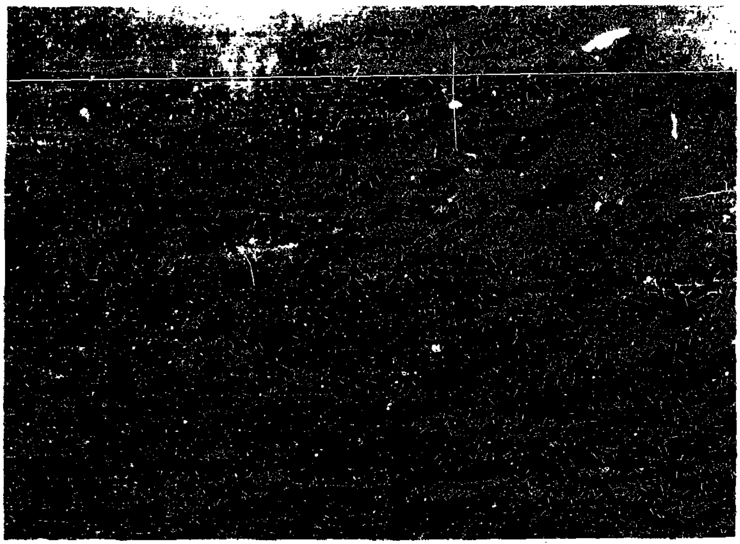

FIGURE 26. Loaded DUKWs ashore at Omaha Beach.

Also, since the captured ports did not become usable as soon as had been planned, the additional load on the DUKW fleet was prolonged. Every available DUKW had to be used day and night, and first and second echelon maintenance was largely neglected.

By the middle of September, most of the DUKWs operating in the United States sector were in very poor condition, this through no fault of the drivers. To aggravate the situation, spare parts were not available except in extremely limited quantities. The reason for this is not apparent; a large supply of spare parts had been accumulated in England in preparation for the Normandy operation, but if they did arrive in France, they did not find their way into the hands of the hard pressed DUKW companies. Field improvisation of spare parts and cannibalization of vehicles unquestionably used up many DUKW hours that could have been better spent on operations.

In spite of all the difficulties, however, the flow of supplies brought ashore 40 per cent by DUKWs was so great that these beaches continued to act the part of major ports into the late fall. These 2,000 DUKWs are reported to have averaged 21 tons per DUKW per day, an astonishing record in the circumstances.

Channel Ports

Cherbourg was captured on June 27, but for several months its value as a port could not be exploited fully because of the heavy damage suffered by its facilities; nevertheless, it at least afforded a smooth water anchorage and it was an important railhead. Logically, one of the first projects at Cherbourg was the construction of a concrete ramp for DUKWs. Several DUKW companies were moved in as soon as possible and the first ships were discharged by them. The DUKWs brought supplies directly from ship to railroad freight car, where cranes transferred the loads.

Later, this same system was used at Le Havre and other Channel ports which, because of damaged facilities, could not discharge ships at dockside.

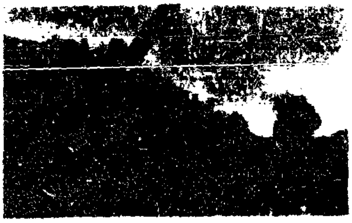

FIGURE 27. DUKWs used as land transportation for infantry troops on German road.

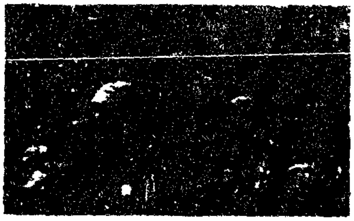

FIGURE 28. DUKW loaded with infantry approaching enemy-held side of Rhine River at Oberwesel.

RIVER CROSSINGS

When port facilities were repaired and the fighting fronts moved farther away, some of the DUKW companies were converted into truck companies. Others retained their DUKWs but were used to provide land transportation along the highways of France and the *autobahnen* of Germany (Figure 27). But even in the heart of Europe, the amphibious qualities of the DUKWs were still needed in the crossing of such great rivers as the Rhine (Figures 28 to 30) and the Danube (Figure 31). Several DUKW companies were used to transport troops and supplies across the Rhine; with the use of the correct river-crossing technique (operations in swift coastal currents had been stressed at the school at Mumbles), no serious troubles were encountered in spite of the swift current. In some cases, Army divisions used DUKWs as part of their standard transportation across lower Germany. Their technique consisted of bringing the assault troops up to a town by DUKW, deploying on foot to capture the town, and remounting on the far side to proceed to the next town. By this means, the difficulties presented by demolished bridges were greatly reduced. Crossing a river by DUKW was found to be an unquestionably better method than using Navy landing craft which had to be transported from many miles away along the narrow and already traffic-crowded European roads.

4.4.4 Pacific Theaters

SOLOMONS

The 451st TC Amphibian Truck Company, the first to be activated and trained at Fort Story, was also the first to arrive overseas. It reached New Caledonia in March 1943 and was ordered by headquar-

FIGURE 29. DUKW transporting troops across Rhine River at Bobenheim, Germany.

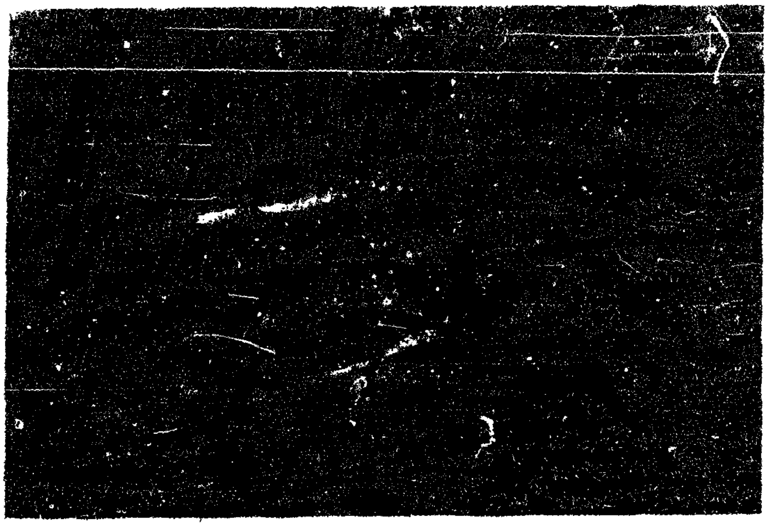

Figure 30. DUKWs must point well upstream when crossing swift current in Rhine River.

ters there to demonstrate the possibilities of DUKWs for ship unloading.

The performance was impressive. A Liberty ship lying a mile offshore in Noumea Harbor was discharged at a rate of 22 tons per hatch per hour (Figure 32), as compared to the usual 6 or 7 tons per hatch per hour when barges were used. The company was sent on to Guadalcanal and for many months unloaded approximately 90 per cent of the rations for more than 100,000 troops on the island (Figure 33).

Figure 31. DUKW crossing Danube River at Donaustauf, Germany, after other means of crossing were destroyed

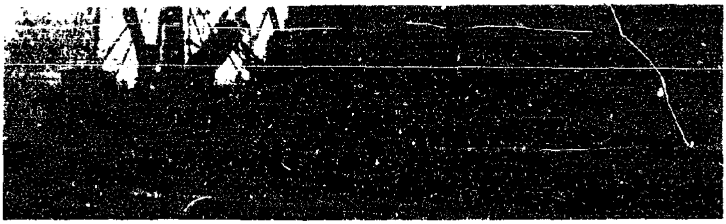

FIGURE 32. First operational use of DUKWs in discharging a Liberty ship, Noumea Harbor, New Caledonia, March 1943, 10 months after project was authorized by Director of OSRD.

In spite of these early excellent results, however, the company's efficiency deteriorated rapidly, partly because of a complete lack of DUKW spare parts but also because of the failure of higher headquarters to appreciate the unfortunate effects of reallocating trained drivers to other jobs, overloading the vehicles, failing to provide sufficient time for proper maintenance, and fever. In September and October 1943, following visits by OSRD personnel to Noumea and to the Solomons, the nonmedical conditions were alleviated to a certain extent, but it was many months later before an effective quantity of spare parts arrived in this area.

In the meantime, other companies arrived, one from *Espiritu Santo* in the New Hebrides, where it had been engaged in ship discharging, and several from the mainland. These companies went to the Russell Islands and to the New Georgia group, where they served to unload offshore shipping. In November 1943, after they had been reorganized on Guadalcanal following visits by the OSRD group, these Solomons-based DUKW companies were given their first opportunity to participate in an assault operation, the landings at Bougainville Island (Figure 34). These landings were made in Empress Augusta Bay, on beaches swept by a heavy surf. No serious difficulties were encountered, however, although many landing boats were swamped. The DUKWs were largely responsible for supplying the assault forces with ammunition and rations.

New Guinea

The first appearance of DUKWs in New Guinea provides a good example of the risk involved in issu

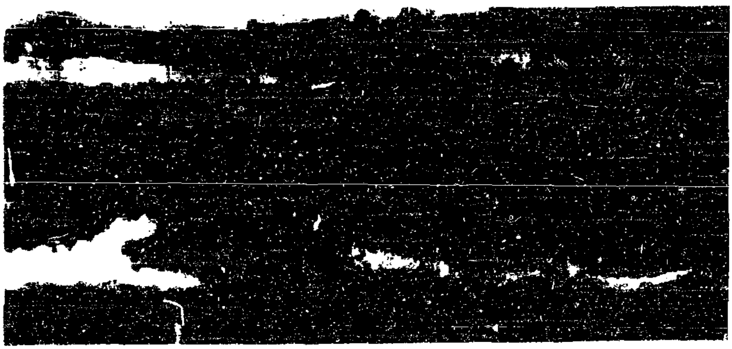

FIGURE 33. DUKWs in operation at Lunga Beach, Guadalcanal

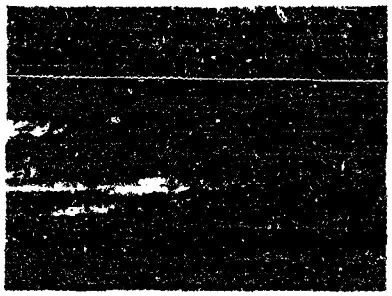

FIGURE 51. DUKW landing on beach in Empress Augusta Bay, Bougainville, Solomon Islands.

ing a new weapon to untrained troops with orders to test it and report on it.

In July 1943, 25 DUKWs were delivered at Milne Bay and issued for trial to the forces discharging ships there. Unfortunately, these troops lacked small-boat experience and did not study the maintenance manual. In 2 weeks the DUKWs were grounded; the report to Headquarters, SOWESPAC, stated that they were unseaworthy, impractical, and more time was devoted to maintenance than to operation.

Because of this report, when the first two trained DUKW companies arrived at Oro Bay, in New Guinea, in September, they too were grounded.

In October, when OSRD personnel arrived at Headquarters, SOWESPAC, it was found that the several hundred DUKWs then in New Guinea were being used largely for long land runs, as a result of the Milne Bay report.

The OSRD mission was requested by headquarters to analyze the amphibious logistics of northern New Guinea and to recommend steps for the full exploitation of the DUKW fleet. Such recommendations[18] were made early in November to Commander-in-Chief, SOWESPAC, G-3, and were immediately acted upon. Nevertheless, neither this vigorous action nor the numerous demonstrations staged by the OSRD mission succeeded in fully overcoming the setback received at Milne Bay, as was determined later when OSRD personnel next saw this DUKW fleet in action, on Leyte in 1944.

With the arrival of trained amphibian truck companies from the mainland, however, the potentialities of DUKWs began to be realized to some extent, and from that time on they participated in amphibious operations whenever available. They started at Milne Bay and Oro Bay, which were being built up as bases for future operations against Japanese-held New Guinea and New Britain. Next, with the capture of Lae, a company was moved there to supply the new airfields at Lae and Nadzab with aviation gasoline. All gasoline destined for forward areas was brought in by Liberty ships in 55-gallon drums. Eighteen of these drums, totalling about 7,500 pounds, made an ideal load for a DUKW, and with the usual shortage of cranes, DUKW A-frames were used at the dumps for unloading.

As in the Solomons, many hours of DUKW operation were lost because of spare parts shortages. So critical did this situation become that DUKW officers went as far as Brisbane in an effort to locate these missing items. There were no spare parts at Brisbane, either. After more strong recommendations were sent back to the United States, some parts eventually did arrive, but in the meantime many DUKWs had been cannibalized in order to keep others operating.

DUKWs were also issued to the Australian Army in New Guinea, and one of its general transport companies used DUKWs to supply forces at Buna while another company worked at Lae. The men in these units were entirely self-taught. Later it was possible for OSRD to work with these companies and correct some of their operational faults in a relatively short time, since both officers and enlisted personnel were of exceptionally high caliber and had previously obtained moderately good results under easy operating conditions. Subsequently, after the Military had been advised on the basis of a preliminary reconnaissance that the conditions were suitable for DUKW operation, these men used DUKWs successfully in the Finschhafen landing.

At the invasion of Arawe, New Britain, on December 15, DUKWs were used not only for supply work but to give supporting fire. Several DUKWs from the 2nd ESB were equipped with launchers for the 4.5-inch beach barrage rocket,* and although this fire power could have been afforded in part by other landing craft, the rocket DUKW could fire either on land or at sea and the results on the Japanese beach defenses were extremely effective.

A request from Headquarters, SOWESPAC, for a total of 1,450 DUKWs was bringing more amphibian truck companies from the mainland, and they were

* See Chapter 16 in this Volume.

playing an increasingly important part in amphibious logistics. At Manus, Biak, Hollandia, and many other landings they served to supply the assault forces (Figure 35). In the assault on the Mapia Islands in November 1944, a battery of 105-mm howitzers was landed in DUKWs and unloaded by A frames. The guns were in action within 15 minutes from the time they were landed.

Even after assault missions, DUKWs were still needed at important points along the New Guinea coast for transportation duties until pier facilities could be constructed (Figure 36). When Headquarters, SOWESPAC, were moved to Hollandia, the continued service of several DUKW companies was necessary to build it up into a base for future assaults on Morotai and other islands to the northward and, eventually, on the Philippines.

FIGURE 35. DUKW used by Signal Corps for laying underwater communications in Admiralty Islands.

ELLICE ISLANDS

As described on page 72, the first Marine Corps DUKW operations were in the Ellice Islands in September 1943. After the men were trained, a company of 21 DUKWs served to unload shipping in the lagoon at Funafuti atoll, which was being prepared as a base for coming assaults against the Gilberts and Marshalls. Here, for the first time, DUKWs operated over bad coral and proved that the findings made in the tests on the Florida Keys the previous February were correct: with skillful operation, DUKWs can be driven over bad coral reefs without appreciable damage or additional tire wear attributable to coral.

From Funafuti, these DUKWs were sent to Nanomea, to the northward, which was occupied without Japanese opposition except for bombing attacks. This small atoll has no passage into its lagoon, and its seaward reef is considered to be one of the worst in the Pacific. Yet, because of its proximity to the Japanese-held Gilberts, it was imperative that an air base be established there. LSTs were brought in as close as possible to the edge of the reef, and the DUKWs discharged them by driving up their ramps on to the tank deck, where they were hand loaded and driven ashore over the reefs.

Unfortunately, DUKWs were not used at Tarawa and in the other Gilbert Islands operations. Their use was rejected in spite of the DUKW operation at Nanomea, which was reported favorably to CINC

FIGURE 36. DUKW transporting troops on north coast of New Guinea. Hard sand beaches along this coast served as temporary roads.

PAC, Pearl Harbor, by the concurring Navy captain who had witnessed these tests and who recommended that the Navy include DUKWs in the plans for forthcoming landings. Many discerning Marine Corps officers, however, had become convinced of the future importance of the vehicles, and, in early 1944, Marine Corps DUKW companies were organized and first used in the Marianas operations.

Marshall Islands

At Oahu, while preparing for the assault on Kwajalein atoll, the U.S. Army 7th Division took advantage of the lessons of Tarawa and decided to capitalize on the valuable tactical use that could be made of DUKWs in landing 105-mm howitzers. Accordingly, four provisional DUKW platoons were organized from division artillery personnel, and one platoon with its 15 vehicles and 3 A-frames was attached to each artillery battalion. The men in these platoons had been given no adequate training in DUKW operation and maintenance, an omission which was later reflected in the condition of their vehicles after a few days of use. Nevertheless, the units landed their artillery at Kwajalein very effectively, having been discharged from LSTs which remained afloat. Although it was not necessary, as was shown in many subsequent operations, each DUKW had its side coamings recessed and its floor supports changed to accommodate the howitzer wheels. No modification is needed if the wheels are correctly chocked.

After completion of their primary mission, the DUKWs were used to unload seven LSTs which served as floating supply depots.[27] The operations at Tarawa had already demonstrated that in atoll warfare a more flexible system than the normal ship to shore operation is necessary. As in the Ellice Island operations, the DUKWs drove directly into the LSTs, and again the system proved very satisfactory. At Burton Island, one of the islets in the Kwajalein atoll, the beaches were under enemy fire for 36 hours and the shore party did not function until the island was secured. During that time, DUKWs carried combat supplies to forward dumps without casualties.

DUKWS would have been even more useful in the Kwajalein operation, however, if they had belonged to a regular amphibian truck company attached to the division. In this way, they could have continued discharging ships after their primary missions were completed. As it was, the DUKWs were wasted to a great extent once the LSTs had been unloaded, for most of the ship unloading was done by a combined te[illegible] of landing craft and tractors a combination far less efficient than DUKWs.

Marianas Islands

The Marianas campaign affords another example of successful DUKW performance on very rough coral reefs. Except for Tanapag Harbor, a few unimportant sections of coast line on Saipan, and two very small beaches on Tinian, the islands are surrounded by barrier reefs.

In these operations were two Marine DUKW companies and one Army company, the 477th Negro-manned unit which later gained additional distinction in the assault on the Kerama Islands. The Marine drivers had had no previous experience with DUKWs and only a minimum of training, but the Army unit, which was attached to the 5th Amphibious Corps Artillery, had received extensive training on Oahu and was in excellent operating condition. The DUKWs were transported in LSTs to their lines of departure and on June 15, 1944, went ashore behind the assault waves of Amtanks and Amtracs. The first DUKW waves were used to bring in troops, then ammunition, and eventually rations and medical supplies. The depths were too great to permit the shipping to anchor offshore, and DUKWs were often obliged to search for their ship as it was shifted by the currents. This made mooring alongside very difficult, especially since the ground swells were heavy.

A great many casualties were brought out from shore by DUKWs. Their land ability was found to be good and another mission was found for them as prime movers for 155 mm howitzers over steep and difficult terrain. Eventually, when the island was secured, DUKWs were used to discharge some of the shipping in the relatively smooth waters of Tanapag Harbor. In the meantime, Marine Corps DUKWs under the 3rd Division participated in the landings on Guam on July 21, 1944 (Figures 37 to 39).

Thirty nine days after the beginning of the assault on Saipan, the same DUKWs were used at Tinian (Figure 40). The night before the landings, they crossed the 7 mile channel from Saipan under their own power, some loaded with 105 mm howitzers and 75 mm pack howitzers and some with ammunition. They anchored that night in the channel and awaited the dawn, which was heralded by a great artillery

Figure 37. Marine Corps DUKW bringing in 105-mm howitzer during Guam landings.

barrage from Saipan. The landing points were two very small beaches which indented the lava coast, one of them 65 yards wide, the other 130 yards. They were so narrow that to have used them for unloading landing craft to any great extent would have been dangerous, for a few broached boats could have blocked the beach (*Figure 41*). On the fourth day a distant typhoon caused heavy ground swells and nothing could operate in the heavy surf except DUKWs, which continued to discharge ships and support the offensive without trouble. For several days, DUKWs and transport planes were the only supply lines open. This was the first occasion on which official Navy recognition was accorded to the DUKW's surf ability.

Shortly after the cessation of hostilities in the Marianas, another outstanding example of the seaworthiness of the DUKW was afforded. A passing typhoon had built up a tremendous sea and a small freighter had been swept on to the offshore reef at Saipan. It hung there with not only spray but solid seas breaking over its decks and washing men into the sea. Some LCVPs were sent out but all returned immediately, except one which was swamped and another which was drifting out to sea with a drowned-out engine. Two LVTs that attempted to put out were also swamped. A call was sent through to the 477th Amphibian Truck Company for some DUKWs. There were so many volunteers from the company that the commanding officer was obliged to order many of his men to remain on shore. Besides the men from the LCVP, approximately 70 men from the

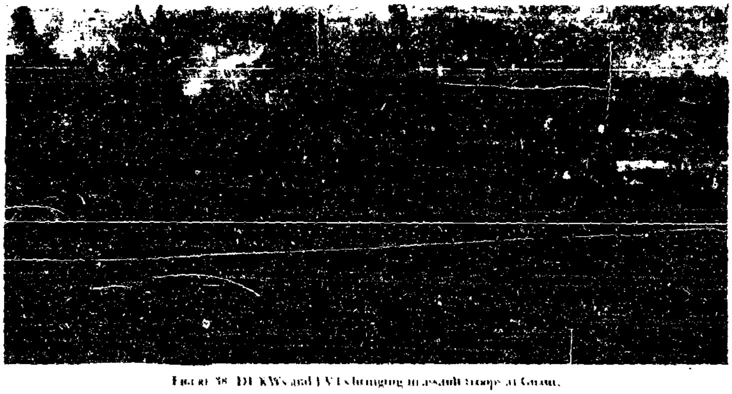

Figure 38. DUKWs and LVTs bringing in assault troops at Guam.

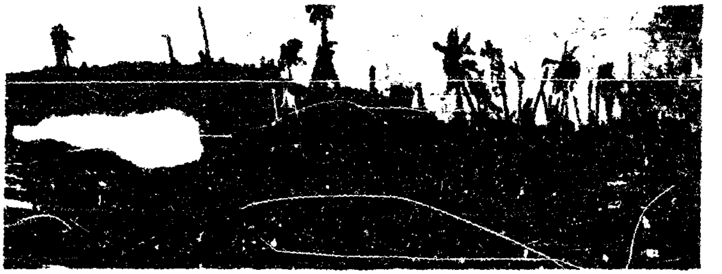

FIGURE 39. DUKWs under fire on beach at Guam.

wreck were picked up alive out of the water. One DUKW was swamped when it was caught in the cross seas close to the stern of the ship, but all its men, too, were saved.

As in many other operations, spare parts were not available during the Marianas campaign in sufficient quantities to keep up with the demand, and a number of vehicles were cannibalized in consequence.

Palau Islands

The landing at Peleliu Island in the Palaus was one of the most difficult encountered by DUKWs in Pacific island warfare. The island is surrounded by an extremely jagged coral reef several hundred yards wide (Figure 42) and on September 15, 1944, when the assault was made, typhoon weather caused heavy swells. In addition, Japanese beach defenses were strong and carefully concealed in the coral outcroppings.

In anticipation of heavy enemy small-arms fire, the two Charleston-trained Army amphibian truck companies attached to the Marine Corps for the assault had piled sandbags around the front and sides of their drivers' cabs. This precaution was an excellent one; unquestionably it saved lives, although nevertheless several DUKW men were killed and many wounded, mostly by machine gun and mortar fire. The reefs contributed to high casualty rates, for the DUKWs were obliged to traverse the worst coral areas at extremely low speeds, and many times DUKWs were hung up completely until they received tow chain assistance from another DUKW.

Besides bringing in the majority of the assault supplies, the DUKWs at Peleliu performed valuable work in evacuating many wounded from field dressing stations, carrying them across reefs almost impassable by any other means, and delivering them to hospital ships.

This effective use of DUKWs over jagged coral during the assault phase against strongly defended positions appears to confirm the assurances given to

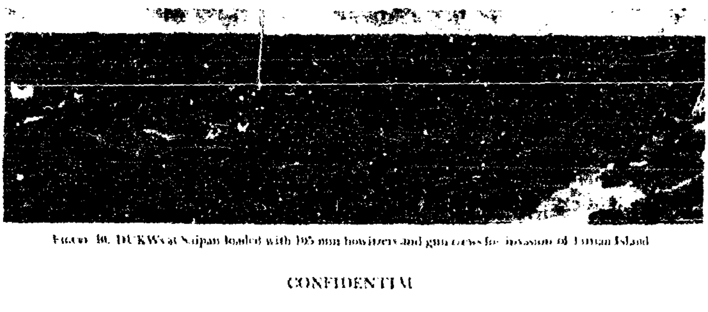

FIGURE 40. DUKWs at Saipan loaded with 105 mm howitzers and gun crews for invasion of Tinian Island

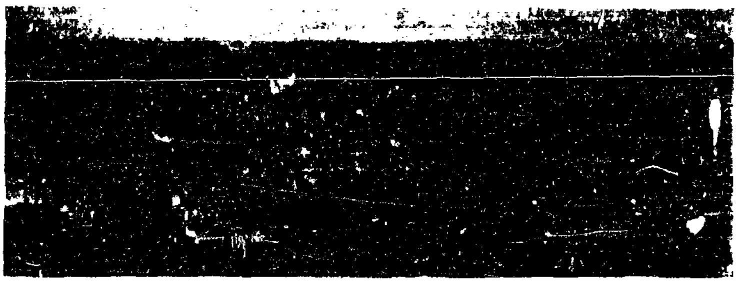

FIGURE 41. DUKWs and LVTs landing on one of two small beaches on Tinian Island. Later, heavy surf forced LVTs to withdraw.

the Navy in August 1943 that DUKWs would prove satisfactory in supporting the assault on Tarawa.

The original units at Peleliu were eventually reinforced by another company which had participated in the landing at Angaur Island to the south on September 17, 1944. Much more favorable conditions had existed at Angaur and the landing there was far less eventful.

PHILIPPINES

In the initial landings at Leyte on October 20, 1944, DUKWs were used on a larger scale than in any previous Pacific operation. Thirteen Army amphibian truck companies participated in the landings near Tacloban and Dulag.[29, 31] Most DUKWs were transported in LSTs, but for the first time some were shipped in LSMs and LSVs, which afforded a very satisfactory means of transporting assault-loaded amphibians to the combat area.

While sea and beach conditions ranged from moderate to good in the Leyte landings, the shore conditions were very poor and heavy rain turned the roads to deep mud. This held down tonnage figures which otherwise might have been very high, since in most cases the ships were able to anchor within a mile of the shore and there was no need to contend with coral. Enemy air action interfered to some extent, especially during the first 2 months; red alerts were frequent and of considerable duration, but DUKW losses were practically nil.

For the first time, DUKWs and Weasels worked together in this operation as two links in the supply chain. To service the artillery batteries, which in many cases were located on steep, muddy hills, the DUKWs brought in the ammunition to a point at which mud halted them, and there their loads were transferred directly into Weasels, which completed the delivery.[c]

As in most operations, there was a shortage of cranes and dumps became very congested. Once again, it was learned that DUKW operations are controlled by the speed at which they can be unloaded on shore. If the dumps are slow, there is nothing to be gained by continuing to add DUKWs to the ship unloading cycle; additional DUKWs will only add further to shore congestion without unloading the ships any faster.

DUKW maintenance at Leyte was quite satisfactory, since operating hours were keyed to the under-

[c] See Chapter 5 in this volume.

FIGURE 42. Unloading of jeeps by DUKW. A frame from other DUKWs during Peleliu landing. Low tide exposes rugged coral reefs which DUKWs had to cross.

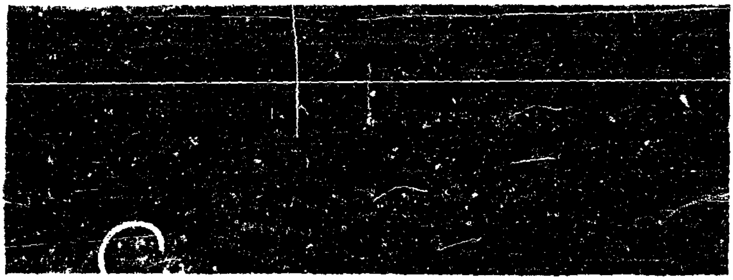

FIGURE 43. DUKWs landing supplies and troops at Puerto Princesa, Palawan Island, Philippines.

strength T/O and the DUKWs were worked on a basis of two 12-hour shifts of 20 DUKWs from each company, with 10 DUKWs held out for regular maintenance checks. This schedule was later moderated to three 8-hour shifts of 22 DUKWs per company—an unsatisfactory arrangement which, resulting in a breakdown in driver assignment, was later abandoned.

Some of the Leyte companies and others newly arrived from other islands or from the United States were used in the subsequent major landings in the Philippines, including Mindoro, the Visayan Islands, and Palawan (Figure 43). On January 9, 1945, three companies took part in the Lingayen Gulf landings in northwestern Luzon. The ground swells were quite heavy and the surf ran 6 to 8 feet high at times, but little trouble was encountered; slow-ups resulted mainly from conditions at the dump, as usual.[30]

When Manila Harbor was opened to United States shipping in early March, it was found that pier installations were so damaged and so congested with sunken Japanese shipping that it was again necessary to use DUKWs to unload shipping (Figure 44). DUKW operations continued there until the end of hostilities.

Iwo Jima

Three Army and two Marine Corps DUKW companies participated in the assault on Iwo Jima on February 19, 1945. Their primary mission was to land the 105-mm artillery battalions and to keep them supplied with ammunition. The three Army companies were made up of Negro enlisted men specially trained at the DUKW school on Oahu for their mission and attached to Marine Corps artillery regiments for the assault phase of the operation. The

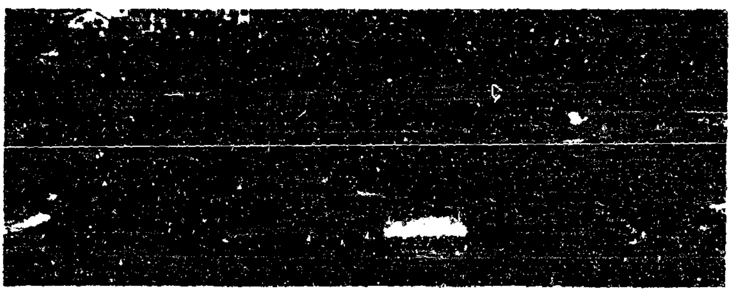

FIGURE 44. DUKWs operating in Manila Harbor, where damaged port installations made them necessary.

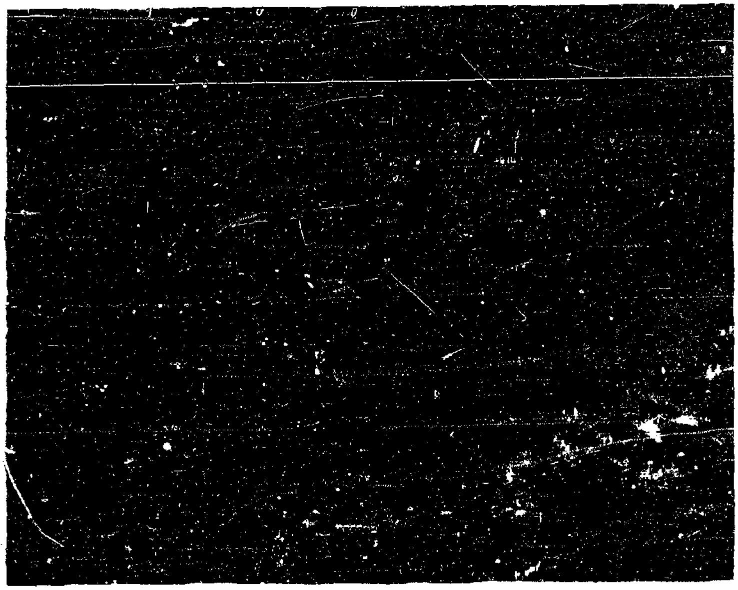

FIGURE 45. Two DUKWs, disabled and partially swamped at Iwo Jima, about to be towed in by tractor.

Marine DUKW companies had no operational experience and almost no training, despite OSRD urging in Washington.

The DUKWs, loaded with guns, ammunition, and gun crews, were discharged into the sea from LSTs at the line of departure some 4 miles out. Most of them went in only a few hours behind the assault waves of LVTs and landing boats, and the beaches were still under heavy mortar and machine gun fire from Mt. Suribachi. Information obtained before the operation had indicated that all beaches would provide firm sand with easy traction for wheeled vehicles. This, however, was found to be completely inaccurate, for they were composed of a fine volcanic ash, so soft that it was extremely difficult to walk in it. Moreover, most of the beaches were so steep that the front wheels of the DUKW would bury before the rear wheels could obtain proper traction, whereupon the vehicle would be swung broadside on by the surf and swamped if it were not towed out without delay (Figure 45). Eventually, a few spots were located where, with tires deflated as low as 5 pounds, the DUKWs could climb out, and at other points tractors were assigned to pull each DUKW up the beach grade as it landed.

Howitzers were unloaded by A-frame DUKWs and set up in battery position, and DUKWs then plied between the batteries and the ammunition-loaded LSTs to bring in 105-mm shells. The LSTs remained at sea for several days; because of the great depth of water, they could not anchor and hold their positions, which made it extremely difficult for the DUKWs to locate them each time they made a trip from shore.

DUKWs bringing the ammunition directly to the batteries were under mortar and small-arms fire most of the time while on shore, and consequently many of the hulls were punctured. Conditions were so crit

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ical and the shore so crowded, however, that in the early phases of the operation it was necessary to send every DUKW back out to sea, regardless of its seaworthiness. Several LSTs had been designated as DUKW repair ships; once aboard, the DUKW hulls could have been easily patched, but in many instances a badly leaking DUKW was not permitted to drive aboard at once and foundered while standing by. Of its 50 DUKWs, one company reported losing 15 which could have been saved if taken aboard the LSTs immediately.

The losses in DUKWs during the first 5 days—well over 50 per cent—were higher than in any other operation. Most of them were due to the causes described above, but other DUKWs were swamped in the heavy surf, damaged against LST ramps while attempting to enter a bad sea, or holed on sunken landing craft near the beach. Casualties among the DUKW drivers were surprisingly light; the companies averaged only 3 or 4 killed or missing and about 10 wounded.

In spite of the combination of difficult operating conditions and high equipment losses, the DUKWs succeeded in bringing almost all of their howitzers to shore, unloading them with the utmost efficiency, and keeping them supplied with sufficient ammunition to be one of the major factors in reducing the enemy garrison.

The Army Negro drivers received high praise for their courage and ability from many Marine officers, including the Commanding General, Fleet Marine Forces. One driver ran out of fuel while searching for a bowser boat out at sea, but although landing craft offered several times to pick him off, he refused to abandon his DUKW and cargo, and drifted many miles to sea for 18 hours before a destroyer brought him in with his DUKW. When ship unloading started, the Army companies introduced the single spring line mooring system, which proved so successful in the heavy swells that the Marines also adopted it.

Maintenance standards were also kept at a level far higher than that in many other landings conducted under easier operating conditions. This was due partly to the superior efforts of the maintenance sections in the DUKW companies, but also to the fact that, before loading at Oahu, they had received from the DUKW school there valuable advice and assistance in procuring adequate supplies of spare parts.

One result of the performance of the Army companies at Iwo Jima was an order from Fleet Marine Forces to the 4th and 5th Marine Divisions to send their DUKW companies to the Army-OSRD DUKW school on Oahu.

At the opening of the garrison phase of the operation, the three Army units were reinforced by an additional company, and all four reverted to the control of an Army amphibian truck battalion headquarters. Thereafter they served to unload Air Corps supplies and rations from offshore shipping.

The Ryukyus

The invasion of the Ryukyus opened on March 26, 1945, with landings by the 77th Division in the Kerama Retto group. The 477th Amphibian Truck Company, attached to this division for the landing and for supplying its artillery, was a Negro-manned unit which had already seen action in Saipan, Tinian, and the Philippines. The DUKWs went ashore on Geruma Shima 2 hours behind the assault waves and unloaded the artillery under enemy small-arms, machine gun, and mortar fire, but without loss.

Subsequently, the 477th moved on with the division artillery to Menna Shima, then to Ie Shima, and finally to Okinawa. On Ie Shima, extensive mine fields were encountered, and although other units suffered severely from personnel and vehicle losses, the DUKWs were fortunate in getting through without serious damage.

On Okinawa, seven Army and three Marine Corps DUKW companies participated in the initial assaults on April 1, 1945. The units landed on the west coast near Yontan and Kadena airfields. Although there was no enemy opposition on the beaches, the coral conditions were extremely unfavorable, the outer edge of the reef being scored by deep fissures and its face pocked for several hundred yards with scour holes and pits where the islanders had cut out blocks for the construction of their tombs. These potholed reefs, over which the DUKWs drove day and night and at all stages of the tide except at high water, when they swam over (Figure 46), caused high mortality in front spring leaves, intermediate axle housings, and other underbody parts; on some days, one company would have as many as seven broken front springs. Accordingly, a new technique was successfully developed for welding broken leaves. DUKWs in most of the companies were already fitted with the propeller guard described on page 68. The other companies, realizing the value of this modification

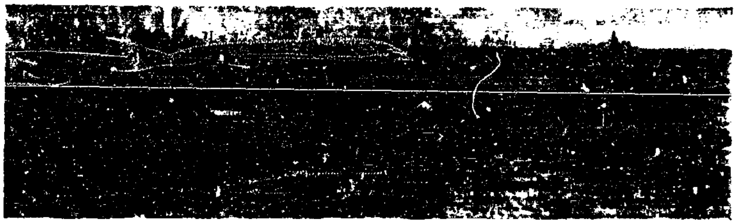


FIGURE 46. DUKWs landing at Okinawa at high tide, when they could cross reefs without touching.

in reducing damage to the propeller, propeller shaft, and strut bearing, installed it as soon as they could.

In order to cut down the DUKW land runs as much as possible, transfer points were set up close to the operating beaches, and trucks were used for land hauls of 2 miles or more. On Okinawa, DUKWs were used in a truly combat role only when they brought the ammunition directly to the batteries during the artillery assault on the main Shuri-Naha lines. (For a noncombat role, see Figure 47.)

The original Army companies, together with the 3rd and 6th Marine DUKW companies, went under the control of two Army amphibian truck battalion headquarters on May 1, together with six more companies that arrived afterwards. Two of these new companies were from Oahu, two more had come directly from training in the United States, and the other two had come from the European Theater by way of the United States. It should be pointed out that the two companies with Oahu training were operating on a full scale within 24 hours of landing, while the other four required a minimum of 2 weeks to prepare and modify their vehicles.

The need for DUKWs on Okinawa was vital.[33] When the last organized Japanese resistance had been overcome in early July, the DUKW companies were required to work even harder, for the island was not only the site of 23 proposed airfields but was also being built up into a major base for the coming assault on the Japanese home islands. Naha Harbor, for which high hopes had been held as a port, was a disappointment, being too thickly filled with the wreckage of Japanese shipping to accommodate anything more than a few LCTs until October at the earliest. All the beaches were fronted by coral which dried out at half tide so that lighters could make only two round trips in 24 hours. Consequently, the services of DUKWs were essential to bring in the great majority of general cargo and Air Corps supplies.

Each company was required to keep a minimum of 35 DUKWs operating around the clock without letup, week after week. This, together with the severe coral conditions and the fact that all but the units newly arrived from the mainland were under strength from the normal attrition of sickness, put such a strain on the companies that they were scarcely able to keep their maintenance up to an efficient level.

At the end of June, however, higher headquarters were induced to order the Engineers to construct ground coral causeways to the edge of the reefs. Deadline rates decreased promptly, though a shortage of mechanics remained apparent. Eleven mechanics, as prescribed in the T/O, are not enough, but by that time most companies were reduced to seven or eight.

To assist in operations, a system of "hoppers" was put into effect. This system, first developed by OSRD at Funafuti in September 1943, consisted of having only one DUKW company man on a DUKW at one time. At shipside, the DUKW picked up a "hopper"—an additional man detailed for this work from the

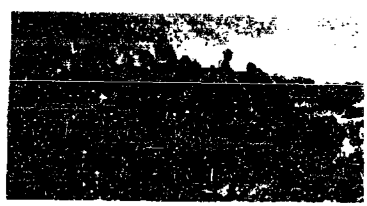


FIGURE 47. DUKWs used on Okinawa to evacuate civilian population.

FIGURE 48. British DUKW landing on hard sand beach at Kyaukpyu, Ramree Island, Burma.

Seabee or port unit operating the hatch—who assisted in mooring the DUKW and in placing the loads. After casting off the loaded DUKW from the mooring line, the hopper hopped to the next DUKW. In this way, even when a DUKW company was as much as 10 per cent under strength, it could just manage round-the-clock operations.

All the DUKW companies at Okinawa and one at Ie Shima continued to operate on a full-time basis up to the end of August, after which the flow of supplies to the island rapidly dwindled. Five of the companies were reconditioned to operate in Korea and to unload supplies for the occupation troops there. Other companies continued to unload ships at various points in the Pacific after the end of the war, but on a very reduced scale.

4.4.5 Southeast Asia Theater

At the Quebec Conference in August 1943, the British requested a future issue of 8,000 DUKWs. Of these, a large proportion was intended for coming operations in Southeast Asia, although it was subsequently realized that the great areas of mud and rice paddies on the Southeast Asia coasts made DUKWs unsuitable for large-scale use in amphibious work there. Eventually, only a few hundred were allocated to this theater.

In late 1943, an amphibious assault on the port of Akyab on the Arakan coast of Burma was being planned. Two RASC DUKW companies were in training in India (see page 72) and a small fleet of LSTs and other landing ships was being prepared for the assault. At the Teheran Conference, however, it was decided that other theaters must be given a higher priority and consequently much of the equipment and supplies intended for Burma operations was diverted to the MTO and SOWESPAC. The actual operation was therefore reduced in scale and had only the limited objective of establishing beachheads on sections of the Arakan coast above Akyab. These were to command the mouths of several rivers up which the Japanese were established. For this operation, 25-pounder artillery was loaded into DUKWs, which in turn were loaded into the three remaining landing craft—one LSD and the only two LST(1)s still in existence. At the landing, the beaches were hard and unobstructed by coral, but inland the presence of rice paddies and swamps made the terrain unsuitable for the use of anything but tracked amphibians. After this section of the coast was secured, it was held for about a year, after which it was expanded by the landings at Akyab, Ramree Island (Figure 48), and Taungup. Several British DUKW companies participated in these assaults and in other operations (Figure 49) which led to the fall of Rangoon in May 1945.

4.5 PRODUCTION

Beginning with an original order of 2,000 initiated late in June and received by General Motors Corporation on July 1, 1942, a total of 27,413 DUKWs was authorized for production. A total of 21,147 units had been built by August 15, 1945, when production stopped.

4.6 CONCLUSIONS AND RECOMMENDATIONS

In this review of the war performance of the DUKW, special attention has been given to the most important obstacles which occasionally blocked its efficient operation. An analysis of this review leads to

FIGURE 49. DUKWs ferrying supplies across river in Burma during British advance on Mandalay.

certain conclusions and recommendations for more efficient solution of similar amphibious problems in the future, whether they concern the DUKW or any related amphibious vehicle, either cargo-carrying or combat.

4.6.1 Design

LIMITATIONS OF THE DUKW

While emphasizing the vital and varied missions the DUKW fulfilled, this review of its performance also discloses certain limitations and shortcomings which could be avoided in future designs. During wartime, it was very logically decided that all available production facilities should be concentrated upon the DUKW; since it was a conversion design based upon a standard chassis and motor, it could be produced with maximum speed and in sufficient quantities to meet the urgent demands of the theaters. In peacetime, however, with time and development facilities available, full study should be given to the advantages offered by a larger amphibian designed from the ground up[g]—that is, with no existing standard land vehicle as a basis.

It was apparent that, as a result of its physical characteristics, even the 1944 production DUKW was not a perfect all-purpose vehicle. Some of its more important limitations are indicated as follows:

1. *Unsuitability for Many Cargoes.* Because of the dimensions of its cargo compartment (82x149 inches), the DUKW cannot transport many types of cargo, particularly (a) 155-mm howitzers, (b) vehicles larger than the ¾-ton truck, (c) crated airplane motors, (d) pilings, and (e) other heavy lumber, building sections, and similar structural material.

At first glance, the fact that the DUKW is limited in the cargoes it can carry would not seem to be a very serious shortcoming. Landing craft and barges are generally available for handling loads unsuitable for DUKWs. But even in the garrison phase of an operation, when convoy-laden ships must be discharged, serious losses of time occur with joint use of DUKWs and lighters. Although DUKWs may commence discharging a ship, they must be replaced by LCTs or other lighterage every time a load unsuitable for DUKWs—such as 2½-ton trucks or airplane motors—is uncovered in the hold. When this barge load has been discharged, the DUKWs, which meanwhile have been lying idle, are called back to continue operations. Additional delays are involved in readjusting cargo booms and mooring lines.

2. *Small Capacity.* By whatever means a ship is being discharged, whether by amphibians or by lighterage, time is lost from the moment one loaded craft is moved away until the next awaiting craft is moved in and moored alongside. With efficient and well trained DUKW drivers, this delay can be cut to a matter of seconds. Nevertheless, it is estimated that the average time lost between DUKWs at shipside is 3½ minutes.

[g] See Chapter 10 in this volume.

(While the cargo capacity of a DUKW ranges between 2 and 5 tons, the average load is 3 tons; thus, for every 3 tons of cargo hauled, 3½ minutes are spent in coming alongside and mooring.) This serves to demonstrate a very definite shortcoming resulting from the small cargo capacity of the DUKW. It should also be noted that this shortcoming has an effect, although to a lesser degree, at the shore unloading point, where additional time is lost while one DUKW moves off and another moves in under the cranes.

3. *Unloading Problems on Shore.* There are several methods of unloading DUKWs when they reach their shore destination. One is the hand system, which involves a large dump crew and is slow and requires very hard work. The other methods call for some kind of lifting device, such as a crane or an A-frame, and consequently numerous delays occur because (a) the unloading devices are not available at the dumps, (b) the unloading devices are undergoing repairs or maintenance, or (c) operators are not available. Therefore, if it were possible to devise some efficient means of unloading amphibians without the use of lifting devices, operating efficiency would be greatly increased.

4. *Low Speed in Water.* Since the DUKW is a conversion design based on the use of a standard land chassis, the wheel suspension, drive shafts, and differentials become wet appendages which must be housed to varying extents. All these appendages produce extra drag and reduce water speed so that in a moderate head sea, for example, the DUKW can rarely exceed 5 mph. This low speed in water precludes the efficient use of DUKWs in discharging ships lying more than 2 or 3 miles offshore, for the number of vehicles required to keep the hatches operating continuously becomes very great.

Thus, in a typical DUKW operation, if a five-hatch ship is anchored 1 mile offshore, only 35 DUKWs are needed to unload her with maximum efficiency. In contrast, if the ship is obliged to anchor 5 miles offshore, 95 DUKWs are required.

5. *Poor Performance on Mud.* While the tires on the DUKW enable it to surpass the performance of almost any other wheeled vehicle on soft ground, it is still unsatisfactory in bad mud. Unless a matting or causeway can be laid down in advance, DUKWs, or any other amphibian propelled by wheels instead of tracks, should not be used in an attempt to cross muddy rivers, swamps, rice paddies, or tidal estuaries.

PROPOSED IMPROVEMENTS

In the case of an amphibian designed from the ground up, some of the inherent shortcomings of the DUKW described above could be avoided. Any new amphibian design under consideration should therefore incorporate the following characteristics:

1. *Larger Size.* An amphibious cargo carrier significantly larger than the DUKW would have a greater cargo capacity, which would permit three needed improvements:

(a) The amphibian could handle many types of loads that cannot be handled by DUKWs, such as 155-mm howitzers, trucks, light tanks, and large crates. Thus each time a heavy load is uncovered, no time would be wasted at a hatch while amphibians are replaced by lighters.

(b) By virtue of its greater cargo capacity, the ratio between the time taken by the amphibian in coming alongside the ship and the tonnage received by the amphibian would be decreased. With a 15-ton capacity amphibian, for example, only 3½ minutes would be lost for every 15 tons of cargo, as compared with 3½ minutes for every 3 tons in the case of the DUKW.

(c) More efficient use would be made of driver manpower, for each amphibian driver would be responsible for the transportation of more cargo.

2. *Stern Ramp.* A stern ramp on the amphibian would ease many unloading problems. Artillery pieces and wheeled or tracked vehicles could be driven or towed out without delay. Palletized loads, fuel drums, and, in fact, almost any type of load could be dragged or rolled out without the necessity of lifting devices. With an adequate power hoist, the type of stern ramp and ramp seal in use on the LVT(3) and LVT(4) would be satisfactory for this purpose.

3. *Increased Water Speed.* An amphibian designed from the ground up could unquestionably attain greater water speed than can the DUKW. Many of the appendages which cause such high resistance in the DUKW could be built inside the hull of a completely new vehicle.

4. *Improved Performance in Mud.* An amphibian propelled on land by tracks in place of wheels could unquestionably operate on muddy terrain impassable for a DUKW or any other wheeled vehicle.

5. *Hull Dimension Limitations.* While the advantages of an amphibian larger than the DUKW are obvious, the following factors must be borne in mind when considering the dimensions in the design of a new amphibian:

(a) Over-all size should conform to the dimensions of the ramp entrances of LSTs, LSMs, LSVs, and other ramped landing ships which might serve as transportation for amphibians.

(b) Angles of approach and departure should be suitable for operation across landing ship ramps, steep beaches, and coral reefs. DUKW angles of approach (38 degrees) and departure (25 degrees) have proved favorable for such conditions.

(c) Maneuverability on land, particularly in dumps, is essential. Over-all width should probably be limited to 114 inches.

(d) Driver's vision should be good.

A preliminary study has already been made of a proposed 15-ton, ¾-track amphibian.[b] Such an amphibian would incorporate the features described above, and its Diesel power would provide the additional desirable features of reduced fire hazards and reduced fuel consumption.

It is recommended that this design be studied further and that a pilot model be constructed so that the possibilities of adopting it as a standard Army amphibian can be more carefully explored.

Such a new amphibian, however, should supplement rather than entirely supplant the DUKW, and any future amphibian production and training programs should include both vehicles. In spite of its shortcomings, the DUKW will always have certain advantages over the larger amphibian. These include:

1. Superior ability to negotiate narrow trails, roads, and bridges.

2. Greater land mobility and speed, making it desirable to use the DUKW for longer land hauls.

3. Longer land life than the ¾-track amphibian, providing another reason for the use of the DUKW on long or rough land hauls.

4. Suitability for stowage in davits on transports and similar vessels.

5. Easier transportation and stowage on deck and in certain types of ship's holds.

If such 15-ton amphibians be adopted, it is recommended that they be operated by amphibian truck companies in the same way as DUKWs, except that a company should have only 25 15-ton amphibians instead of 50 DUKWs. Companies operating the larger amphibians should be placed together with DUKW companies under the operational control of amphibian truck battalion headquarters. Thus, in a typical operation, a battalion headquarters would have three companies operating DUKWs and two operating large amphibians. In this way, the battalion headquarters could control both types of vehicle so that the large amphibians would handle all larger loads and make all the longer sea runs, while DUKWs would be used for the longer land runs.

It is further recommended that such an amphibian be produced in two models, one for combat missions and the other for strictly supply functions. The combat model would be armored in its more vulnerable parts and would be fitted with interchangeable mounts for machine guns, rockets, flame throwers, and other weapons as developed. It could also serve as an amphibious firing platform for the 105-mm howitzer and other artillery pieces.

4.6.2 Modifications

As described in the beginning of this chapter and indicated in Tables 1 and 2, there was a serious time lag in making a change in production, even if the recommended change ever were approved, after field experience had indicated the necessity for it. In the meantime, the only way in which the change could go into effect was by having some exceptionally conscientious ordnance unit in the forward areas or even the DUKW company itself able to find the time, labor, and materials to make the modification.

The subject of production changes on such a vehicle as the DUKW requires a great deal of study in order that the many operational and mechanical difficulties experienced in the past may be avoided in the future. As with the spare parts supply problem, the failure to incorporate prompt changes in production was caused largely by the multiplicity of the channels through which recommendations for changes had to pass.

It would seem that the best means for overcoming this difficulty in the future would be to have accredited and highly competent personnel accompany the vehicle through all its major operations. Such personnel should be empowered to communicate directly with the ordnance authorities responsible for the production of the vehicle in the factories, and these ordnance authorities should be prepared to accept and act without delay or reservation upon any recommendations sent in by the overseas observers. Furthermore, all vehicles which have already left the

[b] See Chapter 8 in this volume.

assembly line should undergo the recommended change at the port of embarkation before they are shipped overseas.

4.6.3 Training

Schools and Programs

As already pointed out above, DUKW training in the United States was not adequate, and as far as possible OSRD gave amphibian truck companies additional training at schools established overseas. This system, however, resulted in duplication of effort and a consequent delay in the time before units were ready for operation. Moreover, fuel, training aids, and school personnel were far less available overseas than on the mainland. In any future training program for amphibian operators, it would be desirable for more realistic and thorough training to be given in the United States so that units would be in first-class operating condition at the time of their shipment to the theaters.

1. Such a school should be established at a location where training conditions are more satisfactory than those at Camp Gordon Johnston. There should be rough sea, heavy surf, strong currents, deep sand, mud, and coral so that drivers may have the chance to train under conditions at least as bad as those under which they will eventually be expected to operate. Fort Ord, California, offers everything but coral.

2. Whenever possible, units should be issued their own vehicles in the United States so that they can train on them rather than on school vehicles and so that they can modify and prepare their own vehicles for overseas operations. It will also be found that interest greatly increases when the students train on the same vehicles which they will use later in combat.

3. Greater attention should be given to training officers so that they will know even more than the enlisted men drivers about the operation and maintenance of amphibians. During DUKW training in the United States, it was found that amphibian truck company officers were required to devote too much time to administrative affairs and not enough to DUKW operations, and many of them reported that they were not even permitted to drive DUKWs. A company cannot be expected to operate at maximum efficiency unless its officers thoroughly understand every aspect of the operation and maintenance of their vehicles.

4. A closer liaison should be maintained with the theaters in which the vehicle is being used. In this way, students can be trained in the latest uses and techniques and can be warned against the mechanical and operational difficulties most recently encountered in the field.

5. A more flexible training schedule should be instituted. By maintaining a close liaison with the higher headquarters under which the units will eventually operate, more information can be obtained on any special mission for which they will be used, and specialized training can be given accordingly. For operations demanding such special techniques as coral driving or river crossing, students should be sent to a location where suitable training conditions exist.

Personnel

In order that future amphibian truck companies can produce maximum results, qualification requirements should be raised for driver personnel. It is not necessary that operators of amphibians should have a seagoing background; it has been found that the best results are obtained with men having truck driving and stevedoring experience. Mechanical aptitude has been found very important. Men should be drawn from Army Classification Group 3 or better. Officers should be selected on the basis of their background and leadership qualifications.

Publications

Even after they had been written, there was a considerable delay in the distribution of DUKW training manuals. This was due primarily to the time taken in putting the finishing touches on illustrations and other details after the text had been completed. As a result, in an attempt to produce a perfect publication, the value of the manual was almost completely lost; by the time the publication reached the men who needed it, the information it contained was largely out of date.

The development of new techniques, the changes in tactical doctrines, the necessity for field work to rectify the most recent mechanical weaknesses, and many other factors all necessitate alterations and additions to an amphibian operator's manual at least every 6 months. Moreover, such information must be in the hands of the using units within 1 month of the date on which it is written or its value will be lost to a great extent.

4.6.4

Maintenance

MAINTENANCE PROCEDURES

While amphibian truck companies were equipped with second and third echelon tool sets, it often happened that higher headquarters forbade the companies to do any work higher than light second echelon maintenance on their vehicles. It was believed that all third and heavy second echelon work on DUKWs should be performed by ordnance companies. This proved a mistake, for such ordnance companies were rarely equipped or trained to perform such work as efficiently as could be done by the DUKW company mechanics with their specialized training and past experience. Moreover, this DUKW repair work was generally farmed out to ordnance companies without consideration of other work on hand, which already might have been more than ordnance could handle expeditiously. It should be pointed out that in such cases, if DUKWs or other amphibians are left standing without attention for only a week, serious deterioration results from salt water corrosion.

In any future operations, it is recommended that amphibian truck companies be permitted to perform all repairs up to fourth echelon on their vehicles. Amphibians requiring such work will consequently be back in operation sooner, and the work will be more satisfactorily performed.

SPARE PARTS

In not one single operation during World War II was the DUKW parts supply system really satisfactory, and in many operations it was nonexistent. The reasons for this situation are manifold, but in most cases it can be put down to the fact that there were just too many channels through which the spare parts had to pass between the factory and the DUKW company motor pool. Therefore, it would seem that if a means could be devised for the elimination of some of the numerous channels, the vehicles would be in a better position to receive their parts when they are needed.

In most cases, DUKW companies were shipped overseas without any spare parts, but with the understanding that they could pick up all they would need in the theater of operations. Naturally, for various reasons they were rarely able to get such parts even when the location and identity of the parts were known. It would be more satisfactory if companies, upon arrival at the port of embarkation, could receive an automatic issue of at least a 90-day supply to take along with their organizational equipment. It is also recommended that the spare parts issue lists as prescribed in SNL G-501[3] be revised to include a larger quantity of those items which have been found in operational experience to need most frequent replacement.

4.6.5

Operation

ISSUE OF VEHICLES

Except in very rare cases, DUKWs or other amphibious cargo carriers should not be issued to units other than amphibian truck companies. If amphibians are required for some special mission besides cargo carrying, such as the transportation or firing of artillery or laying Signal Corps wire, a company or part of a company should be attached to the unit requiring their services for the duration of such a mission and then immediately revert to their normal ship-unloading duties. The DUKWs will thus be operated by fully trained personnel who, moreover, will have better accessibility to spare parts supplies and maintenance facilities. In cases where this system was not adopted, results were unsatisfactory, not only because the DUKWs were poorly maintained and operated, but also because upon the termination of their primary mission they were either neglected in a parking area or used merely for land transportation.

FUNCTIONS OF BATTALION HEADQUARTERS

The functions of an amphibian truck battalion headquarters were originally intended to be entirely administrative. In any operation in which more than two amphibian truck companies were involved, however, the need for a headquarters to control and coordinate DUKW operation and maintenance was so imperative that the battalion headquarters were requested to perform these functions. In cases in which a battalion headquarters was not available, officers from the DUKW companies themselves were detailed to act as a control center, but this was not too satisfactory, since they did not have high enough rank and since, in addition, the companies were obliged to operate short of officers.

In the future, if DUKWs or other amphibious cargo carriers are to be used on a large scale, they should be placed under the operational control of a battalion headquarters. Also, battalion headquarters

should be landed earlier and take control sooner than was the case in many past operations. At Okinawa, for example, although DUKW companies operated from D-Day on, the battalion headquarters did not come in and take over their control until a month later. In the meantime, since their control was completely decentralized, the DUKW companies were not used to the best advantage: periodically one company would be given much more work than it could accomplish, while other companies had DUKWs standing by because of no assigned work, and in most cases an excessive number of DUKWs was requested for individual missions. Individuals not familiar with DUKW operations have not often realized that there is an optimum number of DUKWs which can be efficiently used for a mission. They tend to believe that the greater the number of DUKWs assigned to a ship, the faster it will be unloaded. This is most emphatically not true. Not only are DUKWs wasted in such an arrangement, but dumps and roads are unnecessarily congested.

At Okinawa, if the battalion headquarters had been landed earlier, all the companies could have been released to them as soon as their original assault missions had been accomplished. Then, by coordinated control, the maximum use of all available DUKWs could have been insured.

Weaknesses of Shore Unloading

A study of DUKW operations during the war will disclose the fact that the inevitable limiting factor to tonnage rates were the conditions at the shore unloading points. Especially during the garrison phase, dumps could not or would not receive cargo at a rate equal to the maximum ship discharging rate. Not only did this condition affect DUKW efficiency but it also affected the entire logistic chain.

Even the adoption of a transfer point system did not alleviate matters. This meant merely that while all available land trucks were held up in the dumps, a line of loaded DUKWs would be waiting at the transfer point for trucks into which their loads could be transferred, and meanwhile ships and hatch gangs lay idle. The addition of more DUKWs or more trucks to this cycle only increased land traffic congestion without expediting the flow of cargo into the dumps.

Past shore unloading operations should be studied and the procedures improved so that dumps can be expected to receive cargo at maximum rates at all times. One of the first vital improvements would be a system in which dumps are constantly under the direct supervision of ranking officers who are thoroughly aware of the problems of all the links in the logistical chain and who are familiar with such expedients as the following: (1) The procurement from DUKW battalion headquarters of DUKWs deadlined for water operation, in order to provide A-frames as additional unloading facilities; (2) the procurement of native or prisoner-of-war labor for dump work; (3) the use of a roller conveyor system for the sorting of mixed rations, thus making it unnecessary for a vehicle to go to more than one unloading point in a dump.

Battalion Headquarters T/O

For the battalion headquarters to perform its control functions with maximum efficiency, an additional officer with the rank of captain is essential. He should act as liaison with higher headquarters on the daily assignment of amphibians to their various missions and should compile all operational data and reports.

The T/O should also be increased by the addition of one sergeant and two Tec 5, clerks, general, to the operations section. The inclusion of a medical detachment in the battalion headquarters would also be of great value and should consist of a battalion surgeon and a minimum of 10 enlisted men. Much time and transportation were used in past operations in taking patients from the companies to hospitals. Once at the hospital and regardless of the degree of seriousness of their cases, these patients were generally evacuated. It is safe to say that, instead of being evacuated and leaving the companies permanently short-handed, at least 50 per cent of the personnel evacuated out of amphibian truck companies in Pacific operations could have been returned to their units after treatment by a battalion medical detachment.

Amphibian Truck Company T/O

For round-the-clock operations over an extended period, the strength of an amphibian truck company as organized in World War II is not sufficient. DUKW companies were sometimes so hard-pressed that they were forced to break down their system of having drivers permanently assigned to their own vehicles. This invariably resulted in a deterioration in driver maintenance and consequent higher vehicle deadline

rates, which in turn naturally cut down tonnage figures. A strength of 210 enlisted men is recommended for an amphibian truck company with 50 DUKWs. Instead of 11 as now prescribed, at least 15 of these men should be mechanics. In the case of a company operating 25 15-ton amphibians, the number of drivers would not be as great, but it is believed that at least 20 mechanics would be required for the larger vehicles.

Battalion Headquarters T/E

It is recommended that the following equipment be added to the T/E of the amphibian truck battalion headquarters: one BD72 switchboard, one squad tent, four pyramidal tents, two ¼-ton trucks, and one SCR-608 radio. The last item is essential for efficient control of the operation. With this radio, contact can be maintained with all the company command posts, beach control points, and ship control points.

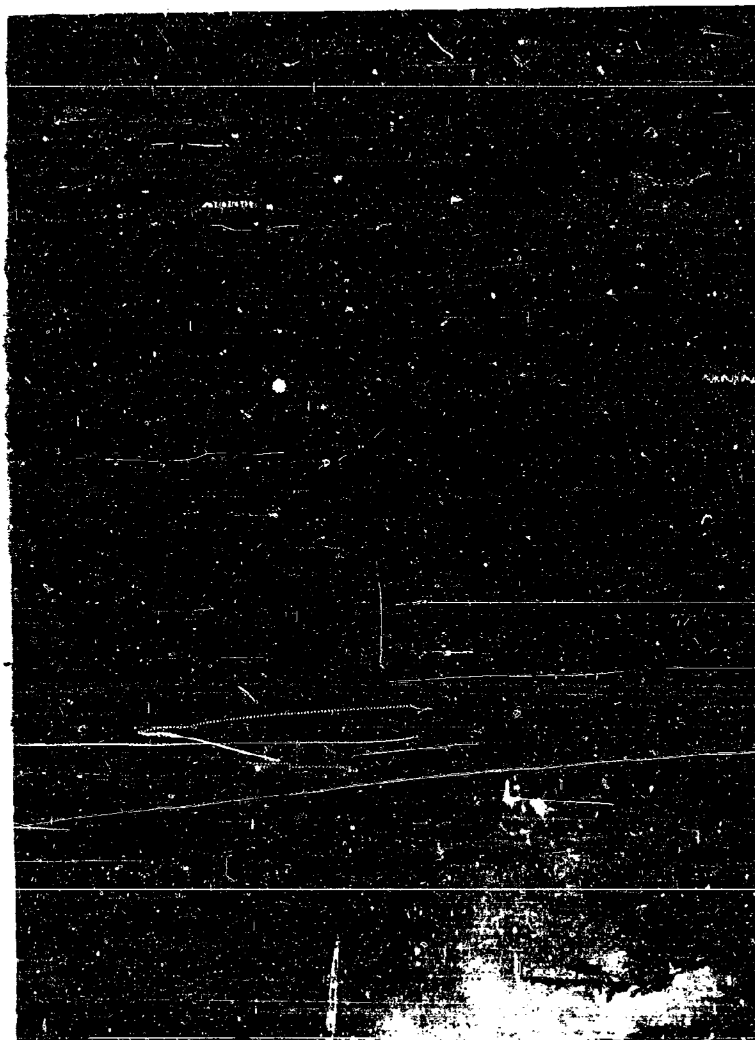
Amphibian Truck Company T/E

It is recommended that the following additions be made to the T/E of an amphibian truck company: one 10-ton wrecker, one 750-gallon, 2½-ton, 6x6 tanker (with pump), one mounted machine shop, one parts trailer, four-wheel, and one 250-gallon water trailer.

In every instance where companies were able to procure these items, they proved of great value and assisted in increasing tonnage rates. If the tanker and the water trailer are not available, then amphibians that might be hauling cargo must be used for the daily transportation of fuel and water to the company area. A wrecker is necessary for salvage and recovery work. On many occasions, DUKWs were lost as a result of swamping and broaching in the surf while hung up on bad reefs or wreckage. Had a wrecker been available, such DUKWs could have been pulled ashore before incurring serious damage. A wrecker is also needed to recover vehicles that have become bellied in soft mud or overturned in ditches, or to tow to the motor pool vehicles that have been damaged by land mines or shellfire. The wrecker can also expedite the repair of vehicles in the motor pool by lifting the front or rear ends or removing the motor or other assemblies.

It is also recommended that the two cranes now included should be eliminated from the T/E of an amphibian truck company. While those cranes were of benefit to the over-all operation, they were a liability to the company itself. When the company is required to operate them, four men are lost as DUKW operators. In most cases, both cranes and men were taken permanently from the company by higher headquarters and assigned to duties which did not in any way concern DUKW operations.

The provision of shore unloading facilities should not be the responsibility of amphibian truck units, except in such cases as the unloading of artillery and ammunition by DUKW A-frame during the assault phase before the landing of other kinds of cargo-handling equipment operated by other Service branches. Such shore unloading facilities as cranes for use in dumps and at transfer points should be included in the T/E of dump service companies or similar organizations.



The Weasel (" . . . any of certain small slender-bodied carnivorous mammals of the genus Mustela . . . very active, bold . . . turn white in winter . . . ") on routine winter snow patrol. Cold winter air condenses exhaust gases into a white vapor.

Chapter 5

THE WEASEL

Summary

THE WEASEL,* a light track-laying cargo carrier, was developed in the spring and summer of 1942 for a military operation against the Germans in Norway proposed for early in the winter of 1943. Before the invasion plans were cancelled, it went into limited production as a vehicle which could negotiate hard ground and snow, climb relatively steep snow-covered mountains, and be transported by air and dropped from aircraft.

This first model, the T-15 Weasel, finally standardized as the Cargo Carrier M-28, was the forerunner of the T-24 Weasel, which was designed in 1943 and later standardized as the Cargo Carrier M-29. With redesigned hull, power train, bogie wheels, track, suspension, and rearrangement of passenger and cargo layout, it went into production for use in snow, mud, swamps, and marshes, where other vehicles could not operate, and served in both the European and Pacific theaters.

Another conversion resulted in the development of the Ark or M-29C Weasel, an amphibious vehicle able to operate not only over snow, mud, and hard ground but also in deep water. It is equipped with special bow and stern cells to provide added buoyancy, and with rudders, skirts, and other shrouding devices to permit water propulsion by means of its own tracks.

Approximately 16,000 units were produced by the summer of 1945 and about 8,000 more were on order. The Weasel was used by the U. S. Army, Navy, and Marine Corps and by Allied military groups as a general purpose vehicle and specifically for evacuation of casualties, wire-laying, reconnaissance across mine fields, supply work in snow and mud, special rescue missions, and transportation of personnel and equipment.

As part of this development, all available snow vehicles were studied, summer test grounds were established in the Columbia Ice Fields in Canada, and a concurrent study was conducted on the physical properties of snow and their relation to the performance of snow vehicles to make possible a prediction, by means of weather forecasts, of the performance of a task force mounted on Weasels, in comparison with the performance of defending ski troops.

* Project OS-65.

5.1 THE PROBLEM

On May 1, 1942, the Director of the Office of Scientific Research and Development [OSRD] was asked by the Chief of Staff, U. S. Army, to develop a snow vehicle to be used in an airborne invasion of Norway in the winter of 1942–43.

In the words of the Prime Minister's Mission sent from Great Britain to expedite this operation, the vehicle should literally convert snow from a barrier into a highway. It should be able to traverse snow, dry land, mud, rocks, and water, and to be carried in gliders or dropped from heavy bombers. Delivery of the first of 600 production models should begin in 180 days for the training of the invasion troops.

This project was assigned to Division 12 of the National Defense Research Committee [NDRC], working directly with the Assistant Chief of Staff, G-4, War Department General Staff. The general requirements were that the new vehicle be able to fit in the bomb bay of the British Lancaster bomber or into the American glider, that it be capable of parachute descent on to bare lake ice, and that it be ready to move off under its own power immediately after landing. (Later specifications called for slinging the vehicle underneath the American C-54 cargo plane.) In snow it should have good speed on the level, high maneuverability in forests, and be able to climb well and to traverse sidehills. It should be able to cross bare rock and railroad tracks, and to get through spring freshets. It should carry a 1,200 pound payload. Since the distance to be traveled by each vehicle in the invasion would be an average of less than 100 miles, of which 90 would be on snow and 10 on hard ground, ice, or rock, the life of each unit was set at only 1,000 miles.

From these general requirements there later emerged the following functional specifications:

1. Maximum beam	60 in.
2. Maximum length	156 in.
3. Maximum profile	50 in.

FIGURE 1. Propeller driven Aero-Sled stalled on slight slope.

FIGURE 2. U. S. Forest Service Snow-Motor, with single 60-inch track and driver's cab supported by rear skis.

FIGURE 3. Eliason toboggan, driven by single 10-inch track, forced downwards by spring reacting against dead weight of vehicle.

FIGURE 4. Tucker Sno-Cat (M 7 Snow Tractor) used by Air Forces for rescue and ground reconnaissance as but later discarded.

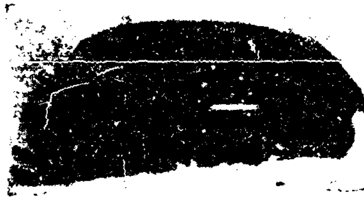


FIGURE 5. The bombardier, driven by tracks and steered by forward skis.

FIGURE 6. Standard ¼-ton, 4x4 jeep equipped with 17.00x20 airplane tires.

FIGURE 7. The Louisiana Swamp Buggy, designed for operation in swamps and sheltered water.

FIGURE 8. The Utah snowmobile, one variety of conventional Caterpillar tractor modified for use in snow, with forward skis for steering.

4. Military payload (including 2-man crew)	1,200 lb
5. Center of gravity	Low as possible
6. Speed on level, in light powder snow	25 mph
7. Speed in water	Nominal
8. Angle of climb on turf	45 degrees
9. Angle of climb on light powder snow	25 degrees
10. Maximum turning radius	144 in.
11. Minimum power-weight ratio	40 hp per ton
12. Cruising radius in rugged country	225 miles
13. Life expectancy	1,000 miles
14. Noise in operating	Minimum

All these requirements were based on operations at an altitude of 8,000 feet, in a temperature range from −40 to +50 F.

It was apparent at once that no existing snow vehicle could meet these requirements, and furthermore that insufficient information was available on the physical properties of snow to permit the application of orthodox design procedures. Little seemed to be known about the shear strength of snow and still less about the change of shear strength as a function of the controlling factors—or, indeed, even the identity of these factors.[14]

5.2 THE T-15 WEASEL

As presented to Division 12 of NDRC, the problem had its fantastic elements. It was necessary to invent a snow vehicle without sufficient engineering knowledge of snow, to decide on the preliminary design before tests on it could be made, to submit this pilot model to field trials in snow in the middle of summer, and to deliver the production model in 180 days, of which an estimated 40 would be consumed in getting out the pilot models and 130 in tooling for production.

5.2.1 Design Procedure

With every emphasis laid on speed and with the full cooperation of British and American agencies which had previously investigated transportation over snow, work began at once on a study of existing vehicles and on a consideration of contractors able to design and build the new device.

THE PRIOR ART

Various types of snow vehicles were already in existence, most of them designed for sport or for rural mail delivery. These, together with experimental equipments previously studied by the U. S. Army Ordnance Department and the Winter and Mountain Warfare Board and by the Prime Minister's Mission, were reviewed at once and the most promising types were selected for test.

A telephone survey of North America showed that the best and most accessible location of spring snow was at Soda Springs, California, and test units began arriving there on May 4. These and later tests confirmed the tentative conclusions derived from a study of the designs of the equipments concerned.

Vehicles driven by an *air propeller*, such as the Aero-Sled (Figure 1), were found to develop high speed on the level, but they have low starting torque even on the level and are unable to climb grades of much more than 3 degrees. Their dimensions inherently prevent use in the prescribed method of air transport. They were the noisiest vehicles tested. Finally, a vehicle of this design with sufficient power to meet the performance requirements on snow and with corresponding propeller diameter would be unable to go through wooded country and, in any event, could not travel over bare dry ground.

Two types of *single-track* vehicles were considered, one with a 60-inch track and one with a 10-inch track. The broad-track design (Figure 2) was eliminated since it could not meet the requirements for speed, climbing, or maneuverability, and the narrow-track design (Figure 3) because it tends to dig into deep snow and into snow-covered grades.

Two types of *double track, ski steered* vehicles appeared to have useful characteristics. The Tucker Sno-Cat or M-7 Snow Tractor (Figure 4), which carries 75 per cent of the weight on a pair of tracks aft and 25 per cent on a pair of forward-running, steerable skis, climbs quite steep grades, performs well in deep snow, and is particularly easy to turn on the level, but as designed does not give enough speed. (A limited number of these vehicles were procured to meet Army Air Forces requirements, but as the result of field experience the design was abandoned.) The Bombardier (Figure 5), essentially an automobile converted into a half track and equipped with skis instead of front wheels, gives high speed on the level but performs poorly on gentle slopes, and has high fuel consumption.

FIGURE 9. Large twin Archimedean screw vehicle on medium moraine.

All vehicles with forward skis were found to be handicapped by an inability to make turns at high speed, particularly when coming downhill over undulating snow. On bare ground, skis have high resistance, and the vehicle is difficult to steer.

It was apparent from their performance that a snow vehicle should be supported entirely on its driving members, and that the location of the center of gravity is a critical factor in its performance.

A vehicle with *very large balloon tires*, such as a jeep with 17.00x20 airplane tires (Figure 6), gives high speed on the level but unsatisfactory performance on even mild slopes. It is halted by gentle hills in light powder snow, and lacks traction for adequate control in steering. Consideration was also given to vehicles with *gigantic balloon tires*, such as the Louisiana Swamp Buggy (Figure 7), but these could not meet the dimensional limitations, presumably would have insufficient traction on sloping ice, and exceeded the weight limitation.

Conventional *Caterpillar tractors* (Figure 8) have low speeds even on the level and are unable to climb snow grades much greater than 8 to 10 degrees. They tend to dig in at the rear when climbing.

Tests with vehicles driven by *twin Archimedean screws* (Figures 9 and 10) showed that this type of design does not lend itself to high speed on level snow, partly because of the high frictional losses inherent in the high ratio of peripheral speed to speed of advance; that they cannot travel at high speed over bare rock or on roads; and that the basic design seemed to necessitate exceeding the allowable beam or profile dimensions. If the engine and cab are located between the screws, the maximum permissible beam is exceeded, and if they are placed above the screws, the maximum profile is exceeded and lateral stability is greatly reduced (Figure 12). Tests of a vehicle driven by a *single Archimedean screw* and stabilized by outriggers (Figure 11) indicate no inherent advantages over the double-screw design.

A study of these and related designs and of the performances in California, which were later confirmed in other field trials, resulted in the conclusion that no available snow vehicle could meet the military requirements.[14]

Basis of the Design

Seven days after work began, the primary specifications for the vehicle were confirmed. From the tests

FIGURE 10. Small twin Archimedean screw vehicle digging into soft snow on slight grade.

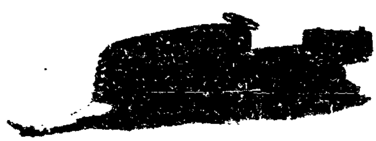
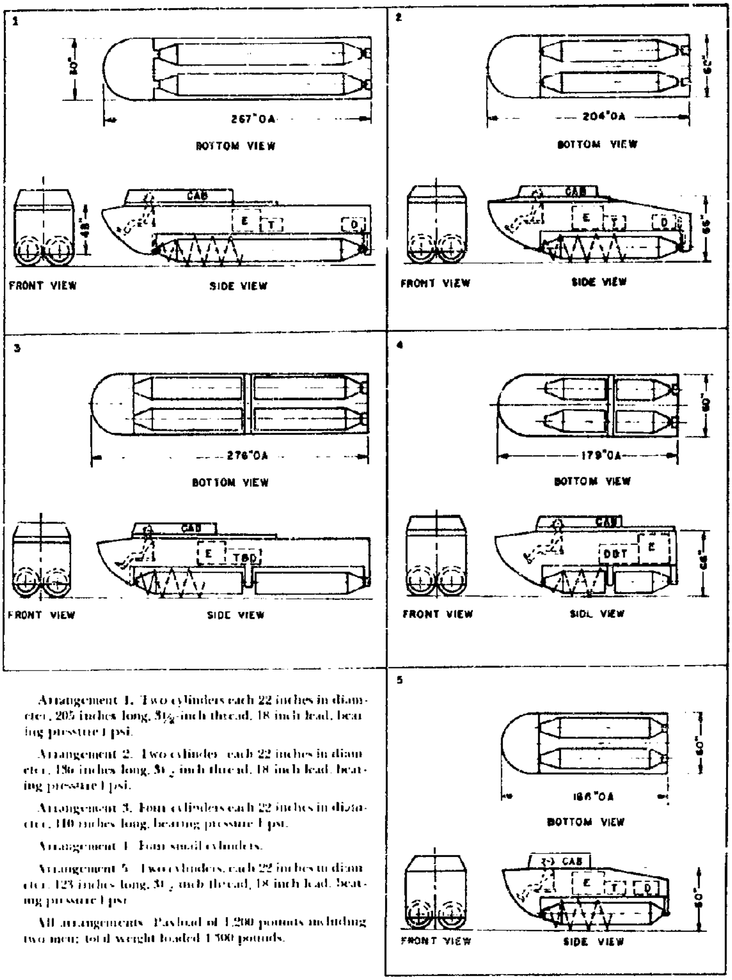


FIGURE 11. Tucker spiral drive snow sled, a single Archimedean screw vehicle stabilized by outriggers.



Arrangement 1. Two cylinders each 22 inches in diameter, 205 inches long, 3½-inch thread, 18 inch lead, bearing pressure 1 psi.

Arrangement 2. Two cylinders each 22 inches in diameter, 156 inches long, 3½ inch thread, 18 inch lead, bearing pressure 1 psi.

Arrangement 3. Four cylinders each 22 inches in diameter, 110 inches long, bearing pressure 1 psi.

Arrangement 4. Four small cylinders.

Arrangement 5. Two cylinders, each 22 inches in diameter, 123 inches long, 3½ inch thread, 18 inch lead, bearing pressure 1 psi.

All arrangements. Payload of 1,200 pounds including two men; total weight loaded 1,500 pounds.

FIGURE 12. Preliminary plans for Archimedean screw vehicles.

in California and elsewhere, it was apparent that air propellers and large tires are impractical, that forward skis are ineffective in steering on sidehill traverses and on downhill runs, and that the entire flotation of the vehicle should be supplied by the tractive means—in short, that a track-laying vehicle would be the most satisfactory solution.

Ignorance of the physical properties of snow made it impossible to arrive at an over-all design by rational steps. It was clear, however, that although the vehicle should preferably have a unit ground pressure no greater than that of an average skier (about 0.5 psi for a 200-pound man on a pair of conventional slalom skis), such a value would be difficult and probably impossible to achieve. Preliminary weight considerations revealed that even a value of 1.0 psi could not be readily attained (such vehicles as the M-4 General Sherman tank and the German MK-VIB King Tiger tank have unit ground pressures from about 14.3 to 14.7 psi), and it was decided to assign no limit to this value but to keep it as small as possible.

Since it was thought that the L/T ratio (L = length of track on ground and T = tread) of a track-laying vehicle on snow should not exceed 2.00 if steering were to be feasible, and since the beam was already limited to 60 inches, it followed that the ground contact length should not exceed 90 inches, depending on the tread. The over-all length should not exceed about 190 inches, depending on the design of the ends.

The center of gravity for climbing should be forward of the longitudinal mid-point of the ground contact area. For descending, it should be not too far forward of that mid-point. For sidehill traversing, it should be as low as possible.

For travel over snow, it seemed that the tracks should be designed to prevent packing of wet snow in them, that the action of the track plates in going over the sprockets should tend to remove snow from between the grousers, and that the depth of the grousers should be considerable. (It was found later, however, that although deep grousers assist somewhat in climbing, they exact a very heavy penalty on hard packed snow, ice, and hard roads because of the concentrated shock loads.)

Accordingly, the War Department General Staff was advised that the design most likely to meet the military requirements appeared to be a conventional track laying vehicle with controlled differential steering, a beam of 60 inches, and a unit ground pressure to be a minimum consistent with good steering.[14] A broad directive was consequently issued to "design, build, develop and test one or more pilot models of a track-laying, airborne, amphibious, snow vehicle to carry a payload of 1,200 pounds up a 25-degree slope in deep snow and to have a maximum speed on the level in packed snow of 35 mph."

This vehicle was christened by Division 12 as the Weasel (". . . *any of certain small slender-bodied carnivorous mammals of the genus Me*[illegible] *. . . very active, bold . . . turn white in winter . . .*"). On May 17, work began on the pilot model designs.[b]

Design Development

The first of the pilot models was developed to meet the original military requirements for use in either snow or water operations, and was to afford an opportunity to determine whether the maximum L/T ratio as informally established by the Army would be satisfactory. Inasmuch as the hull, engine, and drive mechanism presented few new questions for the contractor's engineers, the design problem became essentially a development of track and suspension components.

The track is front-driven by a controlled steering differential. The power plant is located approximately amidships. Eight bogie wheels, arranged in four pairs on each side, carry the vehicle load on each flexible-cable, band-type track. Each pair of bogies is connected by longitudinal semielliptic springs pivotally anchored to suitable outriggers attached to the hull. The suspension provides 89 inches of track on the ground and a 15-inch tread, giving a length of track on the ground to tread ratio of 1.97. Each track is 15 inches wide and, on the basis of area of track in contact with the ground, the unit ground pressure is 2.62 psi at zero penetration. The vehicle, weighing approximately 7,000 pounds with full cargo load, has provisions for a crew of two and storage space in the hull sponsons for their necessary equipment and supplies.[4]

This *amphibious pilot model* (Figure 13) was completed in 38 days. After conferences with the various authorities, it was decided to set its L/T ratio at the high value of 1.97, with an over-all length of 196 inches. This was done partly to explore the upper limit of the L/T ratio and partly to permit incorporation of a propeller for water drive. A few days after this model was started, and because of fears that

[b] This investigation was conducted by the Studebaker Corporation, South Bend, Ind., under OSRD contract OEMsr-685.

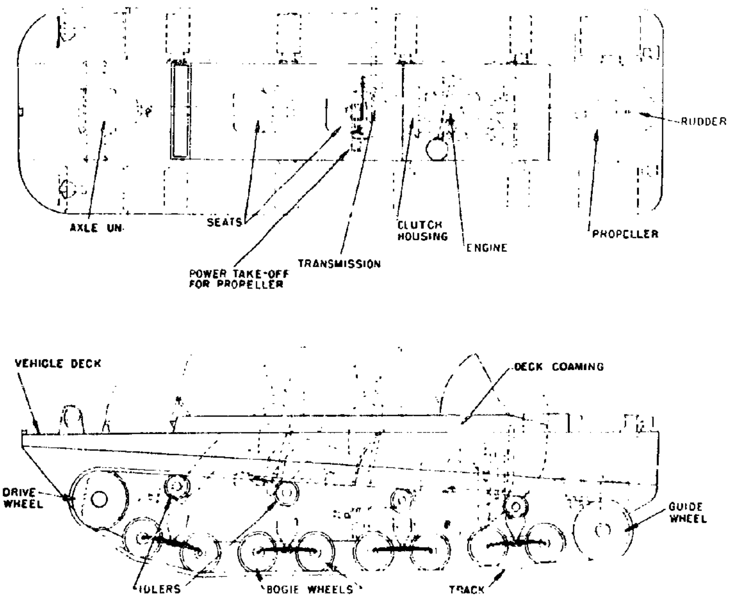


FIGURE 13. Plan and elevation diagram of early experimental amphibious snow vehicle.

its performance would be unsatisfactory as a result of its high L/T ratio and its weight, a second and *non-amphibious* design was begun with an L/T ratio of 1.6 and about half the weight.

The amphibious pilot model has a width of 60 inches, a height of 50½ inches, a tunnel stern, and a propeller driven from a power take-off mechanism for water propulsion, as noted above.

In the first ground tests, the amphibious pilot model was tried in marshy ground and a weedy lake. No difficulty was encountered in negotiating soft ground and weedy water, but as soon as the vehicle was in deep water fairly clear of weeds, steering without grousers on the track was found to be practically impossible. The unit was then taken to the St. Joseph River where, with the tracks stationary and propellers used for propulsion, a forward speed of about 1 to 2 mph was attained, but the vehicle did not respond to the rudder control. No difficulty was encountered in getting it in or out of the water up a reasonable bank from shoal water. In general it appeared to give the required performance over the terrain over which it was tested, but it was found impossible to steer either on land or in water.[15]

In the *nonamphibious pilot model*, the over-all length was reduced, the track width increased, and the L/T ratio reduced to 1.6. Four models were hand made from this second design in 35 to 55 days each, and were eventually put to test in sand and later in snow. These units were used for a quick investigation of the critical components of the vehicle.

In the selection of the most useful *track*, two types were studied: a woven wire mesh type,[*] which was

[*] Manufactured by the Firestone Tire and Rubber Co., Akron, Ohio.

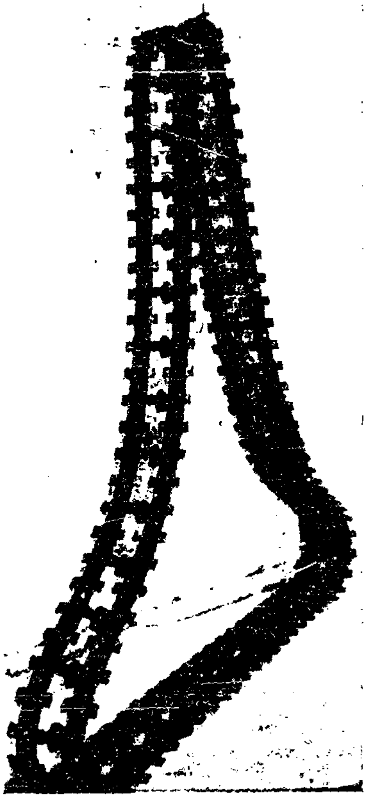


Figure 14. Goodrich semiflexible track bands.

discarded because of excessive friction, and a semiflexible type[4] (Figure 14) made of two molded rubber bands, each reinforced longitudinally by four continuous steel cables, to which are attached a number of steel cross members at 3 inch intervals. The grouser plates and guides are attached to the cross plates.

[4] Manufactured by the B. F. Goodrich Co., Akron, Ohio.

Several different types and sizes of *bogie wheels* and *springs* were tested. Track throwing difficulties encountered with straight bogie wheels led first to the use of angular bogie wheels and finally to angular swivel bogies (Figure 15). The latter is substantially an axle on each end of the spring of the angular bogie, about which the wheel assembly can articulate on a longitudinal axis for a distance of a 26-degree included angle. This permits the track to twist farther before the guides and guide wheels are forced to part, thereby permitting the track to stay on as the angularity increases or until the stops are met.

The bottom leaves of the bogie springs are wrapped around the spring eyes, and clips are added to prevent separating. Steps were added to limit the backward tilt of the front bogie assembly to 12 degrees downward and 16 degrees upward. This prevents buckling under when certain types of terrain are encountered.

The *track idler wheel* assembly was originally made up of a pair of disks so formed that the guides of the track are retained by them in the form of a narrow throat. This was later changed to a wide throat so that the track can readily feed back into place if it starts to come off. Additional flanges were used to carry a fabric belt tire to support the rubber belt of the track. The small lightening holes were eliminated by use of a sharp-edged center disk with large cutaways and spoke reinforcements, while the rubber tire section was changed to a wide rubber band, which proved to be an efficient de-icer.

As with the idler, it became necessary to modify the *sprocket wheel* by making larger openings for ice clearance and replacing the rubber fabric tire with a flat band of rubber.

Since there was no basis to support a rational design procedure, work on the *grousers* and *grouser plates* constituted one of the most extensive parts of the experimental program. The grouser plate started originally as a ribbed steel plate turned up a little at each end and provided with suitable mounting holes. Many types and design variations were made but, with the exception of the addition of a large center clearance hole to prevent ice from packing and a $\frac{1}{16}$-inch coating of rubber on the ground contact side, the ribbed plate type finally used (Figure 16) is little different from the original design.

After a trial of many shapes, the best grouser was found to be a unit 1 inch high, $14\frac{5}{32}$ inches long, and straight across the front or driving side of the grouser plate. A short straight grouser 6 inches long is cen-

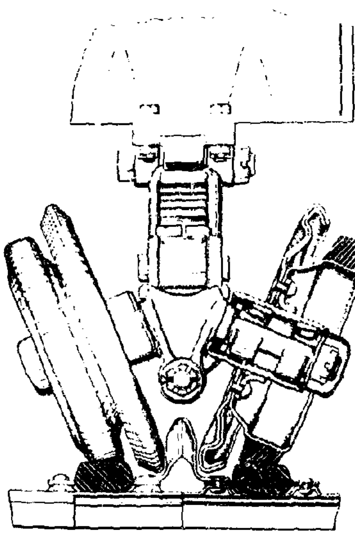


FIGURE 15. Diagram of angular and swivel bogies developed for T-15 Weasel.

trally located at the rear side. These grouser plate assemblies are coated on the bottom with a $\frac{1}{16}$ inch layer of rubber and are permanent with every shoe. Provision is also made for a clamp-on involute type grouser, $2\frac{11}{16}$ inches high, to be attached to every other plate when conditions warrant.

The *track guide wheels* were designed to guide the track at the top as well as to prevent excessive slapping when vibrations set the track in motion. Later a $\frac{5}{8}$ inch endwise movement was provided to reduce wear on the guide wheels.

In early tests, the vehicle displayed a tendency at high speeds to swirl powdered snow, which in turn was sucked into the air inlet and formed ice on the motor. In addition, certain types of snow would be thrown over the rear air chute to the radiator, where it melted and ran into the hull. Metal *snow shields* were consequently provided to protect the engine, and boxes were installed on each side to protect the radiator.

Various types of *steering differential* were considered, and steering ratios from 1.61:1 to 2.14:1 were tried. The most satisfactory was one with a 1.61:1 steering ratio, a transmission ratio of 1.15 high and 2.29 low, an axle ratio of 5.86, and an over-all axle of 6.75 high and 13.5 low.[15]

5.2.2 Test Procedure

While these pilot models were under construction, representatives of Division 12 instituted a search for proving grounds where the models could be tested under appropriate security on various types of snow. With the cooperation of the State Department, observers were flown under diplomatic passport to the Argentine and Chile in Andes, but reported that no suitable areas were available, partly for security reasons and partly because of an open winter.

Another expedition was flown to Alaska for the double purpose of finding a proving ground and making preliminary tests of the shear strength of snow as developed by various alternative grouser designs. In the search by air for proving grounds, the observers looked for any powder snow being blown by ground winds, or the plane was banked at an altitude of 100 feet so that the propeller wash could raise any powder snow present. Exploration of all accessible areas, however, demonstrated that there were no suitable grounds available in Alaska, neither in known glacial areas, where no powder snow was found below an altitude of 8,000 feet, nor in the arid and glacierless Endicott range in northern Alaska, where glaciers had been located by local "experts."

Finally an expedition to the *Columbia Ice Fields* found that the 100 square mile residual continental

FIGURE 16. Inner side of grouser plate (top left), grouser and grouser plate (top right), and assembled unit developed for T-15 Weasel.

FIGURE 17. Loading pilot model of T-15 Weasel into C-47 cargo plane for transportation from South Bend, Indiana, to Columbia Ice Fields.

ice sheet 60 miles north of Lake Louise and 9,000 feet above sea level offered the best proving ground available and accessible in either North or South America. Although the snow was not powder but corn, and obviously due to get wetter, the site was selected for the field trials.

Necessary roads were built on to the snout of the glacier by the Canadian National Park Service, the U. S. Army, and Studebaker, a 5-mile test track prepared, temporary housing constructed and photographic laboratories, garages, and engineering quarters set up. The camps were operated by the 87th Mountain Infantry Regiment. The pilot models were brought there, one of them by plane (Figures 17 and 18), together with other snow vehicles to be used in comparative studies.

During the month of August, numerous test runs were made to determine the operation of the Weasel, its rolling resistance, its maximum speed, its hill-climbing ability, and its maneuverability. After a warm spell, when testing became impossible, the field trials were resumed at the end of September.

When parts failed during the trials, suggested redesigns were telephoned to the factory where improved parts were made up immediately, and the new parts were shipped to the ice fields for testing. By use of air transport service, replacements could generally be obtained in as little as 36 hours, making it possible to maintain the research in spite of numerous failures in the early designs of bogie, track, and suspension parts. A jeep and airplane shuttle service between the ice fields and Toronto made it possible to have 16- and 35-mm films of all tests demonstrated at the camp for analysis within 48 hours, and to present to Army observers a complete record of the performance of all vehicles under all test conditions.

While these tests were under way, another group

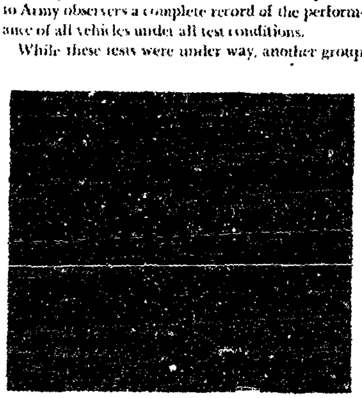


FIGURE 18. Pilot model of T-15 Weasel secured in cargo plane.

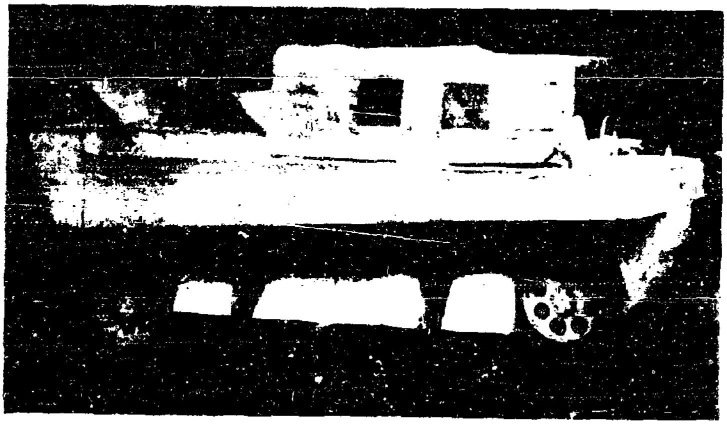


FIGURE 19. Side view of final pilot model of T-15 Weasel.

of investigators conducted a basic study of the physical factors of snow in an attempt to obtain fundamental knowledge to be used in tactical operations with the Weasel and in any future modifications.[c]

In order to determine the possibility of landing the Weasel by parachute, special tests were conducted at South Bend, Indiana, and Wright Field, Dayton, Ohio, under the supervision of the War Department General Staff.

5.2.3 Results

Design of the T-15 Weasel[15]

The final pilot model of the nonamphibious T-15 Weasel is shown in Figures 19 to 22, with a longitudinal section shown in Figure 23. In this model the over-all length is 132 inches, the width is 60 inches, and the height is 67 inches with the top and 49 inches without it. The length of track in contact with the ground is reduced to 62 inches, giving a ratio of length of track on ground to tread of 62/42 or 1.48. The track width is increased to 18 inches, giving a unit ground pressure of about 2.05 psi at 1-inch penetration and with a gross weight (including 1,200-pound payload) of 4,699 pounds. Although the model is shorter than the amphibious unit described above, the cargo volume is about the same.

The center of gravity is about 24 inches above the ground and 46 inches ahead of the center line of the idler.

The suspension consists of four bogies on each side, arranged in pairs and connected together by compound semi-elliptic springs which are pivotally mounted to outriggered cross members forming part of the main hull framework (Figure 21). The final bogie design includes cambered bogie wheels mounted in pairs and pivoted on their connection

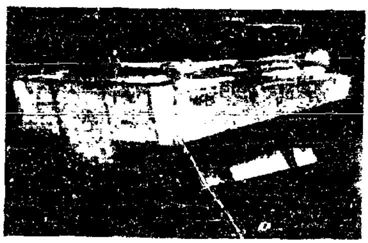


FIGURE 20. Rear view of final pilot model of T-15 Weasel with top removed.

[c] These studies are reported in Chapter 18 of this volume.

FIGURE 21. Front view of the final pilot model of T-15 Weasel.

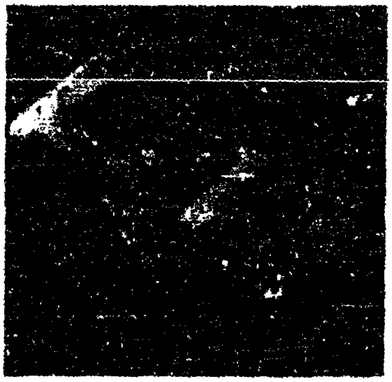


FIGURE 22. Top view of final pilot model of T-15 Weasel, showing accommodations for driver and one passenger.

with the suspension springs. The cambered bogie wheel and guide flange construction provides a line contact with the track guide lugs, and also produces a diverging guide throat which gives more clearance for variations in the angle of approach of the track guide to the bogie over rough surfaces.

The Weasel is powered with an L-head, liquid-cooled, six-cylinder Studebaker Champion engine lo-

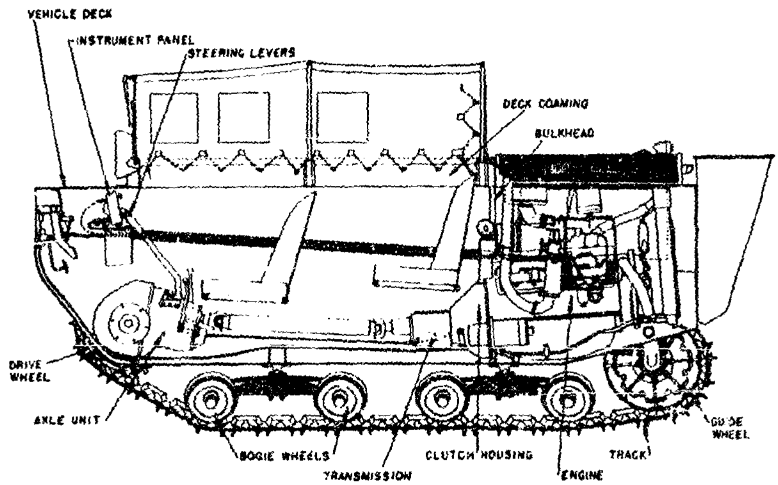


FIGURE 23. Elevation diagram of final pilot model of T-15 Weasel

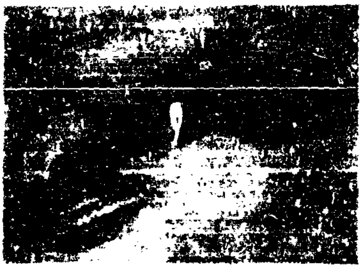


FIGURE 24. Production model of angular swivel bogies used in T-15 Weasel.

cated at the rear of the hull (Figure 25). The flywheel end of the engine is connected to the driving axle at the front by means of a single plate clutch, a conventional transmission, a propeller shaft, and two needle-bearing type universal joints (Figure 26). The planetary type two-speed axle provides differential steering and, together with the transmission, six forward gear ratios and two in reverse.

The hull is welded 18-gage, 0.050-inch thick sheet steel. The rear and side walls of the rear air duct and the front wall of the cargo boxes are made of armor plate to protect the engine cooling system and the rear of the hull.

PERFORMANCE[16]

To test *maximum climb* in the Columbia Ice Fields, the pilot models were driven up Mount Castleguard (Figure 27) on a gradually increasing slope. The angle of grade was measured when the track began to slip so that further forward movement ceased. The maximum grade could usually be climbed only at a very low speed, generally 2 mph, because if the track once started to slip, traction could be regained only by a fresh start. During these tests it was noted especially that the Weasel would not stay in a straight line but would veer off to the right or left depending somewhat upon the general slope as well as upon the ruggedness of the underneath snow crust.

With 1½ to 2 inches of powder snow over crust, the Weasel was able to climb grades up to 21.8 degrees, with an average maximum under these conditions of 19.8 degrees. In 7 to 8 inches of light snow, the average maximum was 24.15 degrees.

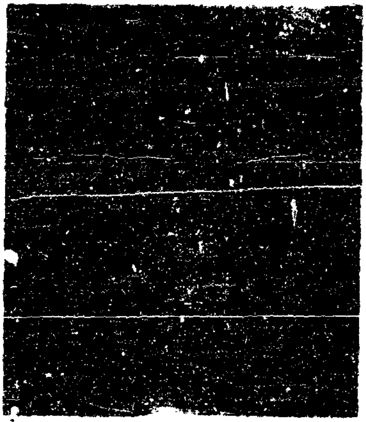


FIGURE 25. Transmission and flywheel end of engine located aft of driver's compartment, T-15 Weasel.

FIGURE 26. Forward end of driver's compartment, showing instrument panel, steering levers, and connections to drive wheels, T-15 Weasel.

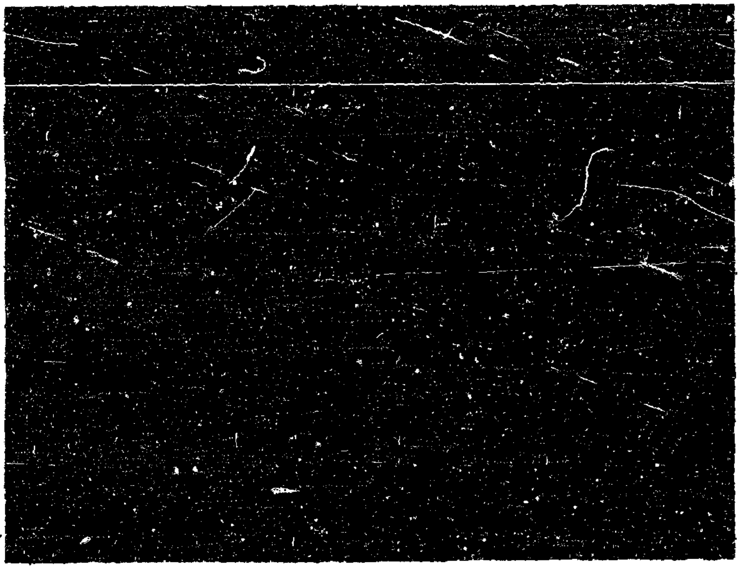


FIGURE 27. Pilot model of T-15 Weasel climbing 20-degree slope on Mount Castleguard, Columbia Ice Fields.

On dry turf (Figure 28) it successfully climbed 45-degree grades.

In *maximum speed* tests, the average top speed at an altitude of 8,450 feet was found to be 20.78 mph in $1\frac{1}{2}$ to 2 inches of powder snow over crust (Figure 29). During these runs, it was noted that, if the snow or ice were rough, the vehicle would pitch at high speeds. While this was not too objectionable under most conditions, it did create a hazard when rough snow and ice or rough moraine was encountered. On

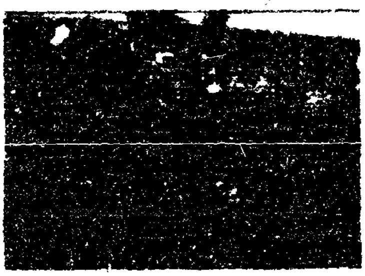


FIGURE 28. Pilot model of T-15 Weasel negotiating 25-degree grade on dry turf.

FIGURE 29. Pilot model of T-15 Weasel can achieve 20.78 mph on level powder snow over crust.

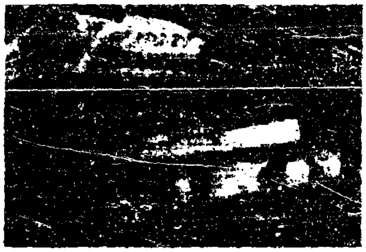


FIGURE 30. "Inherent increase of climb" of about 4 degrees is evident in downhill runs by pilot model of T-15 Weasel.

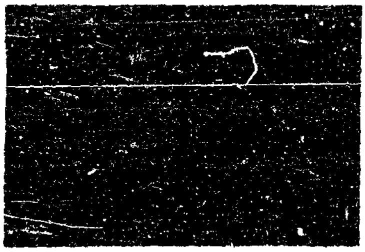


FIGURE 32. Pilot model of T-15 Weasel equipped with 3-inch chevron grousers for operations on the ice of the Saskatchewan Glacier.

a hard, level surface, the Weasel could attain a speed of 32 mph.

To determine *rolling resistance*, the Weasel was permitted to coast down Mount Castleguard (Figure 30) and markers were thrown out at timed intervals. The distances and angles were measured, correlated with time intervals and the other known factors, and the rolling resistance measured. In light powder snow over crust and with the weight of the vehicle 3,838 pounds, the rolling resistance was found to be 504 pounds at 2 mph, 535 at 4, 627 at 8, and 730 at 16.

Under some conditions, the minimum *turning radius* was as small as 12 feet, but under most conditions, depending upon the speed and the terrain, it varied between 11 and 22 feet.

In many other tests, the Weasel demonstrated its ability to negotiate a wide variety of terrain and barriers. Figure 31 shows it under way in deep fresh dry snow, and Figures 32 to 34 demonstrate the action of the flexible track in following contour.

In a test of sidehill travel the Weasel successfully traversed a 16-degree slope at an angle of 3 degrees. On the level and up easy grades, it towed 16 skiers and hauled a sledge loaded to 2,800 pounds.

It floats but has no motive power in water (Figure 35).

The Weasel is able to negotiate ditches with sides up to 50 degrees and steps of 12 to 15 inches, and to knock down green poplars or frozen conifers up to 6 inches in diameter. A green 6-inch elm will bend and throw off a Weasel. Depending on the terrain, it can average 3 to 4 miles per gallon.

In a tactical demonstration, a problem was organized to determine the relative speeds of pursuing skiers and retreating Weasels over varied terrain. The skiers, supplied by the 87th Mountain Infantry Regiment, and the Weasels started at the same time, but

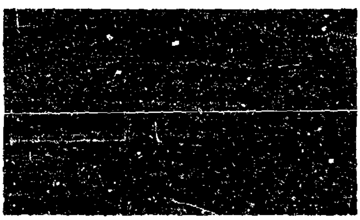


FIGURE 31. Operation in deep, fresh, dry snow indicates need for protecting [illegible] ing" by snow.

FIGURE 33. Pilot model of T-15 Weasel equipped with production grouser and climbing a snow pinnacle.

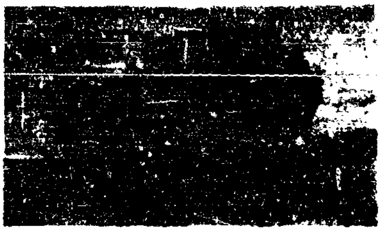


Figure 34. Angular bogie wheels on the pilot model of T-15 Weasel closely follow track in negotiating moraine in Columbia Ice Fields.

Figure 35. In water, pilot model of T-15 Weasel remains afloat but tracks give little net horizontal thrust or steering control.

the skiers took off from a high ridge overlooking the vehicles. Despite the advantage of this *schuss*, they were unable to overtake the Weasels, which retreated to a predetermined strong point 2.9 miles away up a 5- to 8-degree grade and arrived there 41 minutes ahead of the last pair of skiers (Figure 36).

Comparative tests with the Aero-Sled, the Bombardier, the jeep with airplane tires, and the twin Archimedean screw vehicle in 2 feet of partially consolidated powder snow showed that: (1) up a 14-degree slope, none of these vehicles can travel faster than the Weasel, with the Aero-Sled almost as fast; (2) down a 14-degree slope, the Weasel is second only to the Aero-Sled; (3) none of these vehicles can climb better than the Weasel; and (4) none of these vehicles can surpass the Weasel in sidehill traveling.

The effect of the terrain on the performance of the Weasel is shown in Table 1, which gives the maximum angle of climb, maximum speed on level, and average penetration of track for different surfaces.

Table 1. T-15 Weasel Performance on Various Terrains.*

Terrain	Maximum angle of climb in degrees	Maximum speed on level in mph	Average penetration of track in inches
Hard ground	45-48	32	0
Soft ground	(35)	(30)	(1)
Frozen firn snow	32-36	30	0
Spring firn snow	26-31	15-20	1-2
Soft firn snow	15-18	10-12	3-6
Snow with rain crust	32-36	30	0
Snow with sun crust	(24-28)	(15)	(2)
Snow with wind crust	(20-24)	(12)	(3)
Shallow powder (4-inch) on crust	20-24	15-18	2-3
Deeper powder (10 inch) on crust	16-22	10-12	4-6
Shallow powder (4-8 inches)	22-26	12-16	2-5
Deeper powder (10-20 inches)	10-14	4-8	6-12
Deep wild snow (above 24 inches)	(0)	(2-4)	12-15

* See report on snow studies in Chapter 18 of this volume. Values in parentheses ( ) are estimates interpolated from test data.

Figure 36. Pilot models of T-15 Weasel outdistancing skiers in tactical test on Columbia Ice Fields. Even with the advantage of an 1,800-foot schuss from high ridge shown at upper right, skiers were beaten by 41 minutes over 2.9-mile test course.

FIGURE 37. C-54 taking off at Wright Field, Dayton, Ohio, with T-15 Weasel secured for experimental parachute drop.

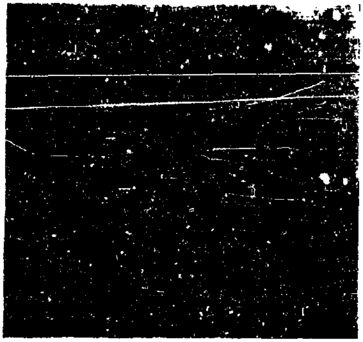


FIGURE 38. T-15 Weasel dropping with cluster of four parachutes.

In an attempt to study the possibilities of dropping the Weasel by parachute, one pilot model was dropped with a cluster of four parachutes from a C-54 cargo plane (Figures 37 to 39). The test did not succeed and the Weasel was seriously damaged, but further studies were made at Wright Field in cooperation with the Army Air Forces, the Army Service Forces, and the manufacturer of the vehicle. Methods were devised for suspending either the T-15 or the M-29 (see below) Weasel from either the C-54 or the British Lancaster bomber. Numerous dropping tests were conducted with these vehicles protected by a specially developed non-rebound, shock-absorbing crash pad made primarily from corrugated cardboard similar to that used in "egg crate" packing and reinforced with plywood web beams. In one series, six T-15 carriers were dropped and two were completely destroyed. In another series, fourteen drops were made from 1,000 to 2,000 feet with each vehicle weighing a total of 4,200 pounds; one of these units rolled over on its side and two rolled on their backs but all were driven away under their own power within 30 minutes. In still another series, four Weasels were dropped and only one casualty was reported—a unit which had previously been landed successfully seven times before. The method of securing these vehicles to the C-54 and the Lancaster, together with the special fairing developed, is shown in Figures 40 to 43. The procedures to be employed in dropping the Weasel by parachute are described in a special publication.[26]

PRODUCTION MODEL

Long before the completion of these tests and the full appreciation of the failures they revealed, tooling was under way on the production models of the T-15 Weasel. Although the planned operation in Norway had been cancelled and some of the pressure removed from this project, the first production models were completed in 205 days—25 days behind the date originally demanded by the Army to meet the

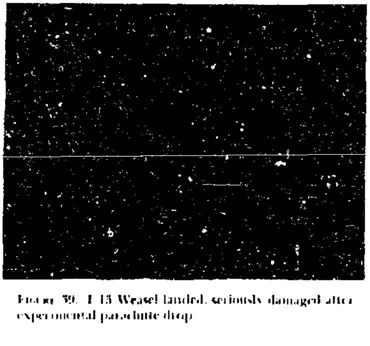


FIGURE 39. T-15 Weasel landed, seriously damaged after experimental parachute drop.

FIGURE 40. New fairing developed for dropping T-15 Weasel by parachute.

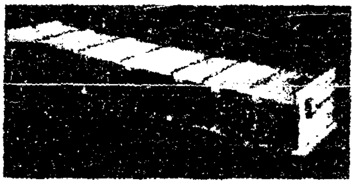


FIGURE 41. New "egg crate" shock-absorbing crash pad developed for dropping T-15 Weasel by parachute.

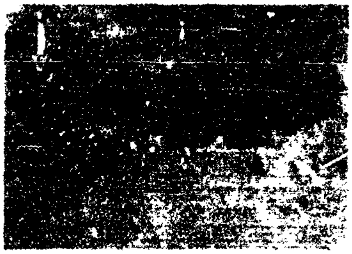


FIGURE 42. British Lancaster bomber carrying two T-15 Weasels with new fairings and crash pads for parachute drop.

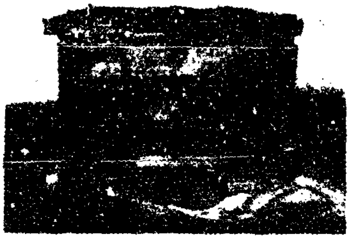


FIGURE 43. T-15 Weasel landed, undamaged and able to operate immediately under own power after drop with four parachute cluster. New fairing and crash pad were used in this test.

schedule for the proposed Norwegian campaign. In some cases the design was slightly modified as a result of early test data, but in general the first models were built on the basis of avowedly incomplete information. Only a few of these production units were used in combat theaters.

5.3 THE M-29 (T-24) WEASEL

5.3.1 Procedure

As service records began to accumulate on the production pilot models of the T-15 and as these were compared with the test results obtained in the Columbia Ice Fields trials, it became apparent that the Weasel might be improved and modified. Since its ground pressure is much less than that of wheeled or heavier track-laying vehicles, it seemed to offer particular possibilities for use in swamps and mud, where these other vehicles cannot operate. Accordingly, a complete redesign was undertaken.

Among the major goals in this new design development were: (1) increased life, (2) reduced rolling resistance, (3) improved cooling to permit operation in the tropics, (4) increased flotation or effective area of track in contact with the ground, (5) improved spring suspension, (6) improved hill climbing ability, and (7) increased cargo capacity.

In order to increase the life of the Weasel, special attention was paid to using larger rivets in the track, strengthening the hull, improving the design of the front eyes of the front and rear springs, and developing a new shaft and auxiliary bracket to prevent failure of the track upper guide wheel and bracket.

The original T-15 has several inherent characteristics of the track and suspension system which contribute to roughness in operation and a resultant high rolling resistance, and tend to reduce speed and acceleration. New types and sizes of tracks, plates, and grousers were investigated in an attempt to overcome these weaknesses. Different bogie wheel and sprocket assemblies were likewise tested.

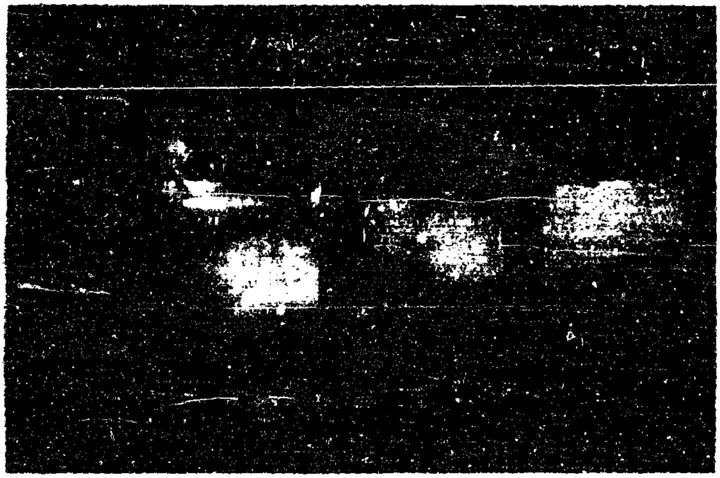


FIGURE 44. Front and side view of M-29 Weasel.

Track width was increased up to 24 inches in order to increase the area in contact with the ground, and experimental models were tested for operation on hard ground and snow, and for hill-climbing ability.

As a possible improvement in spring suspension, transverse springing was tried to give four points of support, a low rate spring, and reactions to vertical load which would be taken in the center of the hull, thus eliminating the inherent weaknesses of the outrigger construction in the T-15 design.

To improve hill climbing ability, investigations were conducted on the advantages of moving the engine to place the center of gravity as far forward as possible, of increasing the power, of using a rear as against a front drive, and of changing the gear ratio combinations.

Various hull arrangements were studied to give increased cargo space and to locate the accessory components more conveniently in the driver's compartment.

Field tests on the redesigned vehicle began early in March 1943, and were conducted first at Kalkaska, Michigan, and later near Bow Summit, 28 miles north of Lake Louise, Alberta, Canada.

5.3.2 Results

DESIGN[28]

The improvements resulting from the design study were incorporated in a model known as the T-24 Weasel which later went into production under the identification of M-29 (Figures 44 to 46). As shown in Figure 47, it differs from its predecessor, the T-15, in having the engine in front and the track drive in the rear. Approximately all of the rear half of the watertight hull is clear space for cargo or special equipment, and seating is provided for three passengers plus the driver.

Sixteen bogie wheels on each side carry the load. These are connected rigidly in pairs by forgings and are pivotally attached to the suspension. The vehicle itself is suspended on four semi-elliptic transverse springs with anchorages which are component parts of the hull framework. This construction reduces the tendency of the track to come off, distributes the load more uniformly over the track area by reducing the unit loading per bogie, and improves rolling resistance by shortening the unsupported track span between bogies.

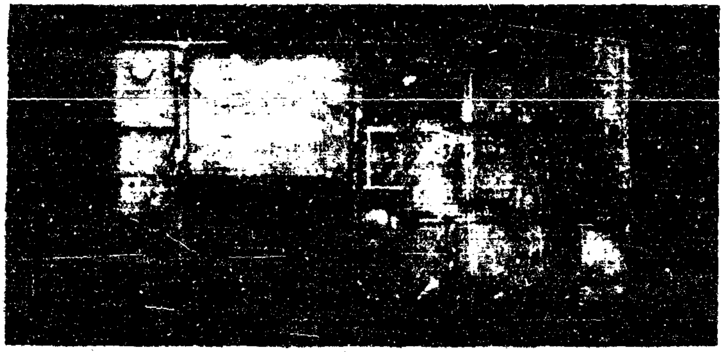


FIGURE 15. Top view of M-29 Weasel, showing accommodations for driver and three passengers.

The center of gravity is moved forward to 52 inches ahead of the center line of the sprocket, giving better load distribution on the track during climbing.

Smaller sprockets, 12 instead of 18 inches in diameter as on the T-15, and smaller idlers make it possible to reduce the sponson height and to seat the driver and passengers over the track without increasing over-all height of the vehicle.

The tread is increased to 45 inches, the track to 20 inches, and the length of track on ground to 78 inches, increasing the ground contact area to 3,125 square inches, in contrast to 2,232 for the T-15.

The over-all length of the hull is 119 inches, the width is 60 inches (65 inches including rub rails), and the height is 71 inches with the top up and 51 inches with both top and windshield down. Total gross

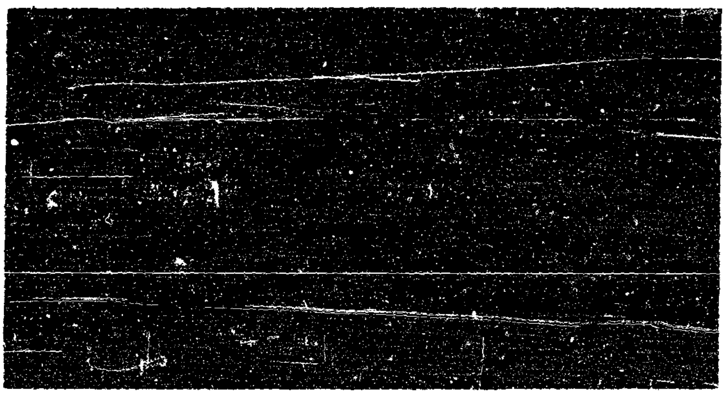


FIGURE 16. Rear and side view of M-29 Weasel.

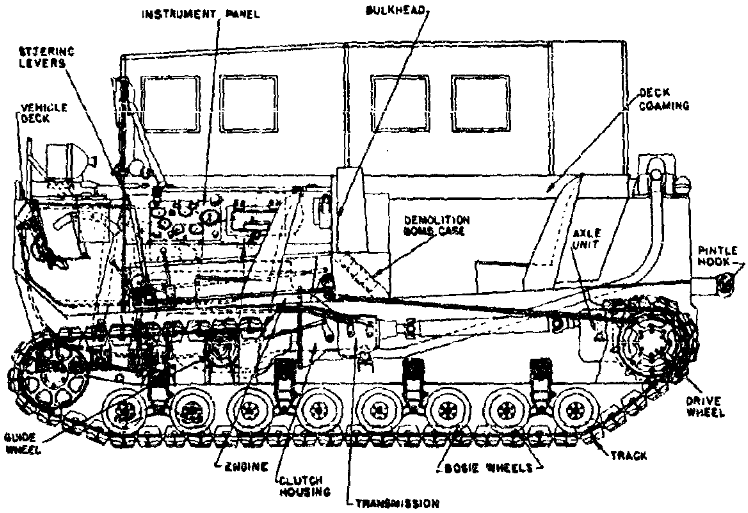


FIGURE 47. Side elevation diagram of M-29 Weasel.

weight, including a 1,200-pound payload, is about 5,200 pounds, with a unit pressure at 1-inch penetration of 1.7 psi.

PERFORMANCE

Operating tests showed that the T-24 or M-29 Weasel is faster, has less rolling resistance, can climb better, has lower fuel consumption, rides better, has larger cargo space, and performs better than does the T-15 or M-28 Weasel.

Maximum speed on a hard surface, as measured at an altitude of 5,000 feet, is 36.0 mph. *Rolling resistance*, as measured on the two models on gravel, is about 315 pounds at 2 mph, 320 at 4, 345 at 8, and 400 at 16 for the M 29, as compared with about 370 at 2, 420 at 4, 475 at 8, and 550 at 16 for the T-15.

In one Lake Louise test for *climbing ability* in snow, an M-29 Weasel with a test weight of 5,950 pounds successfully climbed a 24-degree hill in 8-inch powder snow over hard crust. Under the same conditions, a T-15 Weasel lost steering on a 16-degree hill and failed to climb the grade. In tests in 2 inches of fresh snow over ½ inch of crust over deep wet corn snow, an M-29 Weasel successfully climbed a 17-degree hill, while a T-15 failed and broke into the layer of corn snow.

In general, under comparable conditions, the M-29 can climb about 20 per cent better in snow than can the T-15 and can travel about 12 per cent faster on hard ground.

The track, which in the T-15 has a specified life of only about 10 miles on a hard surface, gives from 1,000 to 2,000 miles of service in the M-29. (This was increased to 3,000 miles by July 1945.)

PRODUCTION MODEL

The M-29 went into production on August 30, 1943, with an original order of 1,000 units. This was later increased to a total of 4,102 by May 25, 1944.

5.4 THE M-29C WEASEL (ARK)[c]

5.4.1 Procedure

In addition to using the Weasel on dry land, snow, and mud, it soon became desirable to convert it into a self-propelled, amphibious unit which could oper

[c] Projects OD 65, AC 60.

FIGURE 48. Equipped with outboard motor, M-29 Weasel floats in water and achieves speed of 1.5 mph.

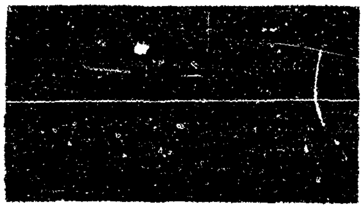


FIGURE 49. M-29 Weasel equipped with experimental track skirting for study of water propulsion by submerged tracks.

ate in deep water, and which could be used for the rescue of airplane crews forced down in jungles, swamps, mud flats, and other inaccessible areas.*

In April 1943, a standard M-29 Weasel was tested in a lake and performed quite unsatisfactorily. Its maximum speed was found to be about 1.5 mph, and it was totally unresponsive to steering by differential track speed. Detachable outboard motors were then investigated both as auxiliary and as primary means of propulsion (Figure 48), but these were abandoned because they increased the speed only to about 2.3 mph, they were easily fouled by weeds, and they could not be readily stowed during land operations without seriously reducing cargo space.

The preliminary tests had indicated that although the vehicle itself was not propelled at any great speed by tracks alone, the tracks apparently moved considerable amounts of water. This confirmed the belief that the low vehicle speed was due to opposing thrusts of the propelling and return track discharges. Track skirting and false bow and stern assemblies were therefore installed for an investigation of minimizing the return track thrust. The skirts and baffles were arranged to reduce the inflow of water to the return track, and the baffles were arranged in the false bow structure to cause the discharge jet to impinge on the shrouding forward of the track and thus regain in

* This phase of the investigation was conducted by The Studebaker Corporation, South Bend, Ind., under OSRD contract OEMsr-1166, in cooperation with Sparkman & Stephens, Inc., New York, N. Y., under OSRD contract OEMsr-151.

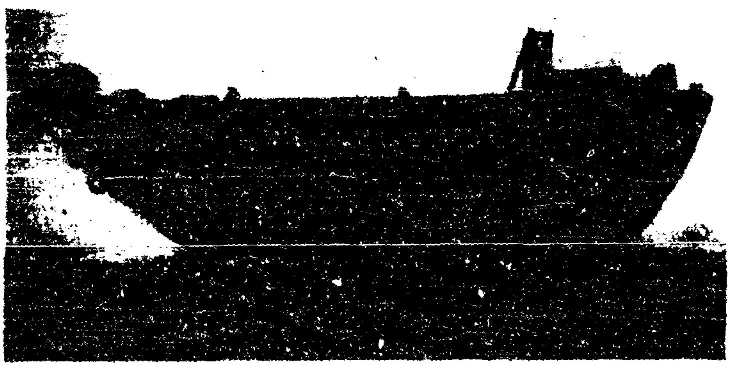


FIGURE 50. Side view of M-29C Weasel, with rudders lifted.

FIGURE 51. Side and rear view of M-29C Weasel, with rudders lifted and top up.

FIGURE 52. Side and front view of M-29C Weasel, with top up.

the form of a forward thrust some of the energy lost in the return track.

The experimental unit (Figure 49) was tested in water and gave a speed of about 3.5 mph. The track could not be run at maximum speed because the volume of water pumped by the return track, together with the discharge velocity impinging on the bow skirt, was directed upward and tended to swamp the vehicle. A critical lack of sufficient freeboard was self-evident. Steering, however, was greatly improved. No increase in weed-fouling was noticed, and the 8-inch clearance provided by the skirt did not detract from normal cross-country performance.

It was tentatively concluded that (1) a completely submerged track could be used as the sole means of propulsion, (2) a maximum water speed of 4.0 to 4.5 mph could be expected with properly designed equipment, and (3) bow and stern tanks are necessary to increase freeboard and to increase the propulsive force of the water moved by the track.

Bow and stern cells and side skirts were then designed and constructed primarily as a subassembly

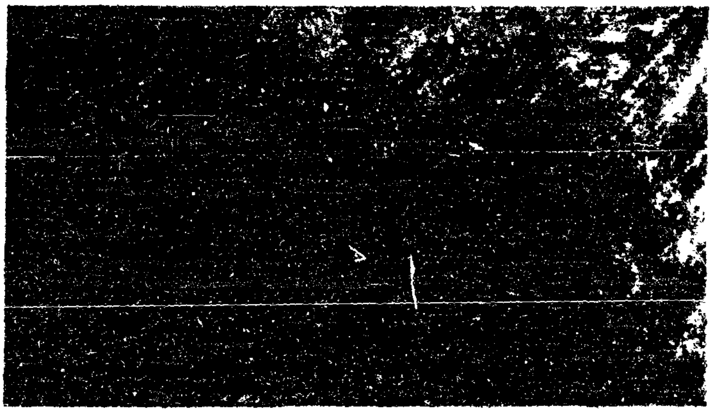


FIGURE 53. Top view of M-29C Weasel, showing bow and stern cells, capstan, twin rudders lowered into place, and accommodations for driver and three passengers.

FIGURE 51. Instrument board and controls in driver's compartment of M-29C Weasel.

which could be installed in the field. The lower portion of the bow cell, on which the return track discharge impinges, was shaped in the form of a Pelton cup, directing the discharge water downward and rearward. Compound vanes were also added to the discharge section of the bow cell and arranged to discharge a portion of the return track water outboard and rearward. This arrangement tends to reverse the direction of return track discharge, thus producing a forward thrust on the vehicle.

The triangular stern section was mounted so that the bottom edge of the stern sheet was tangent to the track and could act as a stripper, baffling part of the slipstream away from the return track chamber. The side skirts were made removable and designed to give 1-inch clearance at the track edge. In addition, a removable baffle extending outward from the hull bottom was installed to prevent recirculation of water between the upper and lower tracks. Provision was made for installing a wood spar or filler in the return track section between the inside edge of the track and the side of the hull center section immediately below the sponson floor. The installation of the filler block confined the return track water and also gave additional buoyancy. Later a bow modification was added to give greater bow buoyancy, added length of hull, and reduced water resistance.

Various combinations of all these accessories were tested to explore the effect of increased discharge of the return track, track skirting, and additional buoyancy in the bow cell. These tests showed:

1. Removal of the outside track skirting reduces

FIGURE 52. Front view of M-29C Weasel, showing final design of bow cell.

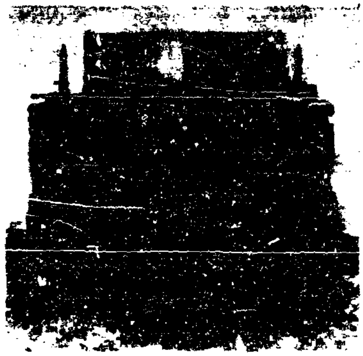


FIGURE 53. Rear view of M-29C Weasel, showing stern cell and rudders lifted.

maximum vehicle speed by approximately 33 per cent and also results in considerable loss of steering control.

2. Inside track skirting, when applied as a horizontal baffle, does not materially affect speed, but the addition of a sponson tank indicates an increase of about 2 per cent in maximum speed.

3. Increased area of discharge in the bow gives an increase in speed.

4. Added length of hull obtained by bow shape gives a slight increase in speed. However, a departure from a scow bow to a sharper bow does not seem desirable in an amphibious vehicle because the former is preferable when the vehicle is operated in brush or jungle.

Various rudder arrangements were tested for steering response, with the best being two rudders, mounted as high as possible, which swing freely on hinges to prevent damage from rocks or logs, and which can be pro - cted for land operations by lifting and stowing them on the deck.

5.4.2 Results

From the results of the studies came the design of the production model of the Ark or amphibious M-29C Weasel. Views of this model are shown in Figures 50 to 56, with a longitudinal section and plan view given in Figure 57.[2,39]

This unit, like the nonamphibious M-29, has a front engine and rear track drive. It is larger than the nonamphibious unit, with an over-all hull length of 174 inches, an over-all hull width of 60 inches, and an over-all height with top and windshield up of 71

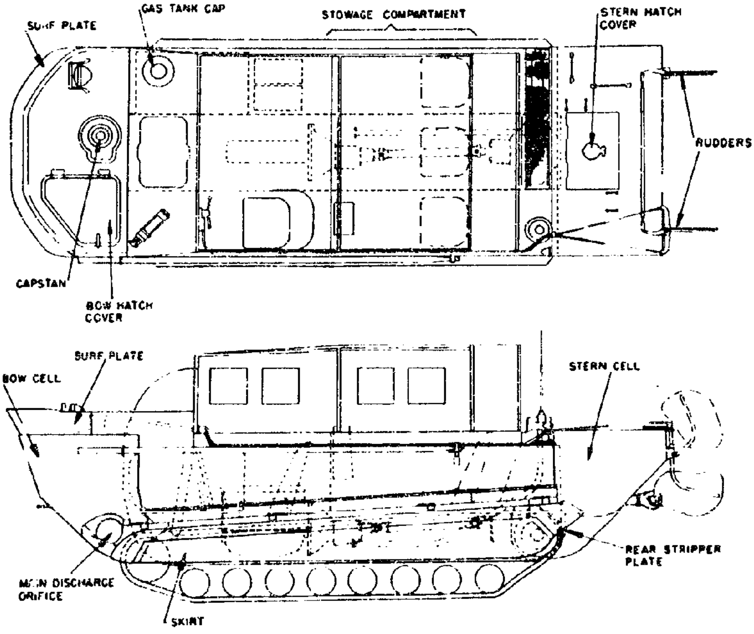


Figure 57. Plan and elevation diagram of M-29C Weasel.

Table 2. Comparison of Weasel Models.

	First pilot model (amphibious)	Second pilot model (non-amphibious)	T-15	M-29	M-29C
Over-all hull length, *without* pintle hook, in inches	196	132	132	119	174
Over-all hull width in inches	60	60	60	60	60
Height, top and windshield down, in inches	50.5	49	49	51	51
Height, top and windshield up, in inches	67	67	67	71	71
Weight light in pounds	5,800	3,200	3,400	4,000	4,800
Payload in pounds	1,200	1,200	1,200	1,200	1,200
Weight loaded in pounds	7,000	4,400	4,600	5,200	6,000
Track width in inches	15	18	18	20	20
Length of track on ground in inches	89	60	62	78	78
Tread in inches	45	42	42	45	45
L/T	1.97	1.6	1.48	1.73	1.73
Ground contact area for zero penetration, in square inches	2,670	2,160	2,232	3,125	3,125
Unit ground pressure for zero penetration, in psi	2.62	2.02	2.06	1.56	1.91
Ground clearance in inches	12	12	12	11	11
Cargo floor area in square feet		7	7	20	20
Cargo space volume in cubic feet		16	16	30	30
Center of gravity above ground, loaded, in inches		20	22	21	21
Center of gravity ahead of sprocket center line, loaded, in inches		16	16*	52	52
Angle of approach in degrees		60	60	90	47
Angle of departure in degrees		70	70	60	36
Maximum speed on land at sea level, in mph		33	32	36	36
Maximum speed in water, in mph	4.5	†	†	†	4
Grade ability on hard surface, in degrees		45	45	45	45
Horsepower per ton gross weight at 3,000 foot elevation	15.7	21.7	23.6	21.1	18.3

* Ahead of idler center line.
† Indeterminate and negligible.

inches and with top and windshield down of 51 inches. Total gross weight, including 1,200-pound payload, is about 6,000 pounds.

At zero penetration, with a track width of 20 inches, the unit pressure is 1.9 psi. The center of gravity is about 21 inches above the ground and 52 inches forward of the center line of the rear sprocket. The ground clearance is 11 inches.

Performance tests showed that the M-29C can achieve a speed of 4 mph in water and 36.0 mph on land, and can negotiate snow, mud, and other barriers as well as can any of its predecessors. It was operated by both civilian and military personnel in field tests in deep and shallow water, sand, surf, swamp, marshes, rice fields, snow, hard ground, and in areas overgrown with weeds and marsh grass, and in climbing and traversing snow-covered hills and muddy banks.

Further tests indicated the M-29C would probably be useful for carrying personnel, pack howitzers, mortars, stores, and ammunition, for evacuating casualties, for reconnaissance in difficult terrain, for towing small trailers or guns, and for laying wire.

Production Model.

The M-29C went into production on May 25, 1944, with an original order of 3,400 units. This was later increased to a total order of 19,619 by April 25, 1945.

5.5 MILITARY USE

5.5.1 T-15 Weasel

With the abandonment of the proposed operations in Norway, the T-15 was used in only one significant campaign—the reconquest of Kiska in the Aleutian Islands. Although this was technically the "frozen north" for which the T-15 had been developed, the vehicle was actually used not on snow but on hard, rocky beaches which the tracks and other structures were unable to survive, and on soft, deep tundra which it negotiated very well, although all wheeled vehicles were mired.

The T-15 was also used for training purposes, particularly at the AAF Arctic Training Center in Colorado (Figure 58), where it was employed by men later assigned to ground patrol and rescue work along arctic air routes.

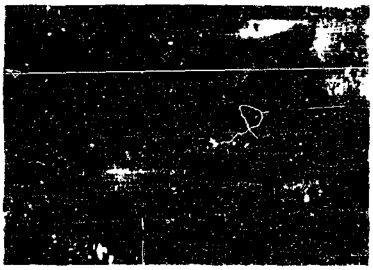


FIGURE 58. T-15 Weasel as used at AAF Arctic Training Center, Colorado, with solid cab top for winter operations.

5.5.2 M-29 Weasel

The second model of the Weasel, the M-29, was found to be a more rugged and more valuable vehicle. It was tested in training centers in the United States (Figures 59 to 61), and adopted by a special British scouting group training in Canada as the only motorized vehicle which could negotiate the Banff-Lake Louise area in winter. In the northern United States, Canada, and Alaska, it was used by the Air Transport Command to make possible efficient ground transportation, and patrol and rescue work during winter along the U. S.–Siberia air route.

FIGURE 59. Like its predecessor, M-29 Weasel can negotiate steep grades both uphill and downhill.

In Europe, the M-29 made its first appearance at the crossing of the Rapido River in Italy where it was used for hauling ammunition across the muddy approaches to the river. Later it was used on the Anzio

FIGURE 60. At Camp Hale, Colorado, M-29 Weasel (with trailer) serves for training and for transportation in winter.

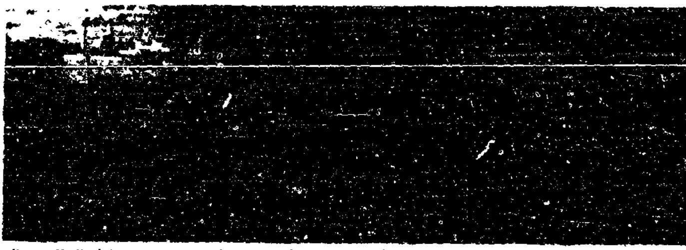


FIGURE 61. Training Army personnel to operate M-29 Weasel with guide lines attached to controls, a procedure developed originally for use in the vicinity of crevasses and later used in the European Theater for reconnaissance through mine fields.

FIGURE 62. M-29 Weasel used for wire laying operations in snow, European Theater of Operations.

FIGURE 63. Near Roer River in Germany, a 9th Army M-29 Weasel fills its major role: evacuating casualties

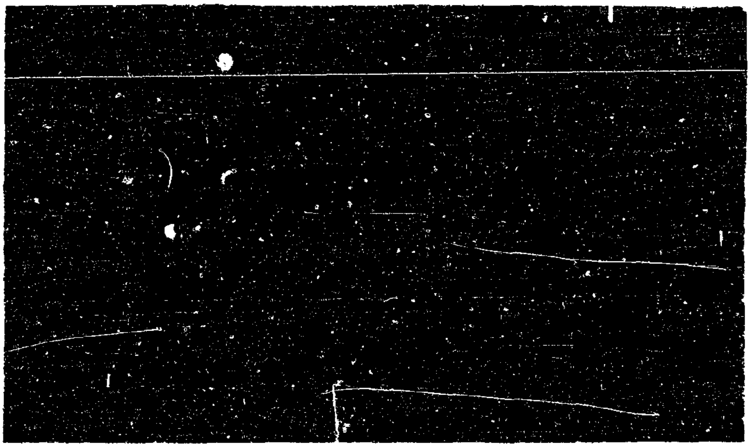


FIGURE 64. M-29 Weasel gets through mud at Ordnance Field Depot in France.

beachhead to rescue 2½-ton trucks mired in the Italian mud, and in the assault on Mount Cassino. In the invasion of France, it was used in the first D-Day landings at Utah Beach in Normandy.

As one of the very few vehicles which could operate satisfactorily in snow, the M 29 found extensive use during the winter campaigns in Italy, France, and Germany (Figure 62). Medical units reported that while slippery roads and snow-drifted fields often stopped jeeps, trucks, half-tracks, and even tanks which were pressed into service, the Weasel was the only vehicle which could get through without bogging down and causing loss of time and lives. Snow drifts 4 or more feet high and even mines buried in frozen ground failed to stop it, its ground pressure not being great enough to detonate the mines.

In mud, swamps, and shallow water, however, the Weasel appeared to its best advantage (Figures 63 to 65). Some units used the M-29 to supply detached posts which could not be reached by any other vehicle. Others used it in shallow water to move supplies and evacuate wounded. It was widely used for wire-laying operations by the Signal Corps, as well as for reconnaissance, message carrying, and occasional emergency transportation of personnel.

In one operation in the Hürtgen Forest, where it was believed that no motor vehicle could negotiate the terrain and only horses could get through, the failure of necessary pack saddles to arrive made it essential for the Weasel to attempt evacuation of casualties. The Weasel was found to perform completely satisfactorily.

In other areas the Weasel was used in mine fields for the detonation of anti-personnel mines. Equipped with rollers in front of each track and additional

FIGURE 65. A flooded road in Germany provides sufficient traction for an M-29 Weasel.

FIGURE 66. M-29 Weasel brings in prisoners on hard road in Normandy (harder on Weasel than on prisoners).

rollers towed to cover the area between the tracks, the vehicle was remotely controlled by operators walking 20 to 30 yards behind and using light ropes attached to the steering levers as "reins."

The M-29 made its least auspicious showing in Normandy, where it was driven on hard-surfaced roads in the hedgerow country (Figures 66 and 67). In spite of the fact that the vehicle was not designed for this type of operation, having a design life of only a few hundred miles on hard roads, it was used until the tracks fell off in some cases more than 900 miles.

Reports from the Pacific and China-Burma-India theaters also indicated the value of this vehicle, particularly for evacuation of casualties and wire-laying operations over terrain impassable to wheeled vehicles and to heavier track-laying units. The M-29 proved so useful in evacuating casualties across the swamps and rice paddies of Leyte and Okinawa that the Army and Marine medical groups rarely had sufficient Weasels on hand to meet the requirements. At Iwo Jima, its performance over soft volcanic dust made it invaluable for evacuation of wounded personnel and general cargo carrying, and it was often the only vehicle of any kind which could get over this type of ground. At Saipan, Guam, Tinian, Kwajalein, Bougainville, Luzon, and Mindanao, the

FIGURE 67. M-29 Weasels used as troop carriers in break-through at Saint Lô.

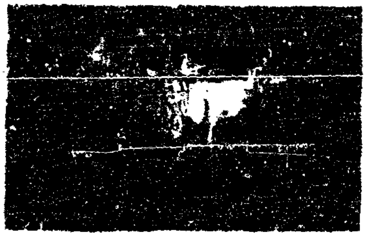


FIGURE 68. In field tests on Roosevelt Island in Potomac River, the M-29C Weasel penetrates weedy marshes.

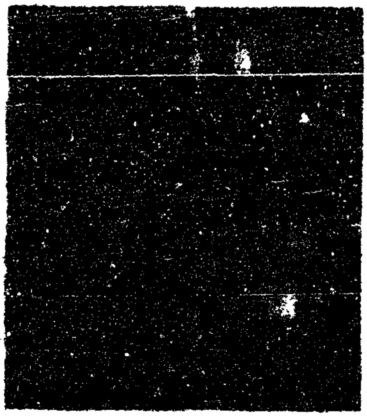


FIGURE 69. M-29C Weasels operate successfully in swamps and bayous of Louisiana.

Weasel was employed successfully over many types of terrain, although only in small numbers.

Objections to the use of the M-29 included statements that it was too noisy, sounded like a tank, and therefore drew *enemy* fire, it was not protected by armor, and it could not climb every steep incline.

6.3.3 The M-29C Weasel

Field trials and demonstrations of the amphibious M-29C Weasel (Figures 68 to 70) quickly indicated the additional usefulness of this vehicle, notably as a litter carrier for evacuation of wounded over difficult terrain (Figure 71).

Although it saw action in Europe (Figures 72 and 73), particularly in the invasion of Walcheren Island and the crossing of the Rhine, it was in the Pacific that this amphibious model was applied most dramatically. Like the M-29, the M-29C was used in small numbers at Mindanao, Kwajalein, Saipan, Guam, Tinian, and Burma, but at Iwo Jima, Leyte, and Okinawa it was employed in large fleets with excellent results. In the jungles of Bougainville and the swamps, marshes, rice paddies, and river country of Leyte, Luzon, and Okinawa, it was employed where no other vehicles—often not even the nonamphibious M-29—could operate (Figures 74 and 75).

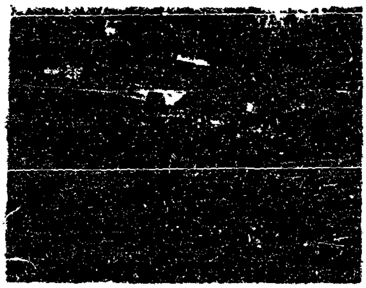


FIGURE 70. This M-29C Weasel towing a 105-mm howitzer went through this Louisiana mudhole 18 times before becoming mired.

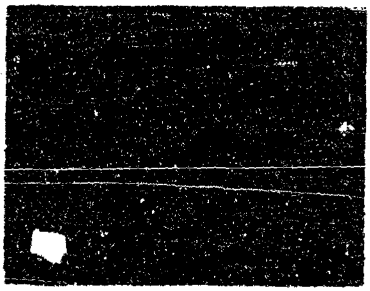


FIGURE 71. Special equipment makes M-29C Weasel useful for evacuating casualties over difficult terrain.

Figure 72. British-manned M-29C Weasels and LVT's land on Walcheren Island in assault on Antwerp.

On Bougainville, although only limited numbers of the M-29C were available, these units demonstrated their versatility by carrying men and supplies through jungles, mud, sand, and water where no other single vehicle could do the job, and even by towing guns through obstacles which hopelessly mired other vehicles (Figure 76).

As with the M-29 in Europe, the M-29C Weasel in the Pacific was peculiarly suited for wire-laying over terrain in which a single vehicle often had to negotiate mud, water, and stretches of hard roads. Since it could cover terrain inaccessible to any wheeled vehicle and since it could be adequately waterproofed and blacked-out for night operation, it was widely used as a mount for vehicular radios, carrying the necessary equipment for a three-man radio team which would otherwise require a ¼-ton, 4x4 truck plus a trailer.

On Leyte, it was reported that the M-29C was the most valuable of all cargo carriers, and that it was

Figure 73. American M-29C Weasel crossing Kocher River at Forchtenberg, Germany.

FIGURE 74. M-29C Weasel makes a difficult river crossing on Bougainville.

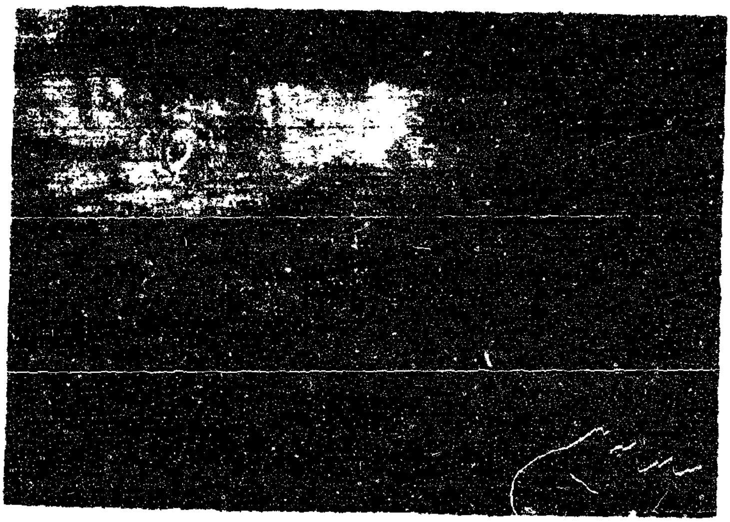


FIGURE 75. M-29C Weasel with amphibious trailer gets through deep water in Solomon Islands.

Figure 76. A mudhole on Bougainville is no different from one in Louisiana to M-29C Weasel.

improbable that combat, movement, and evacuation could have been sustained without it (Figure 77). It

Figure 77. In conquest of muddy Philippines, M-29C Weasel was a link in logistic chain from ships to DUKWs to forward mortar batteries in hills.

was the only vehicle which could operate in the cross-country maneuvers which characterized a large part of the campaign; it consistently negotiated rivers, rice fields, swamps, mud, and sand without difficulty, and even operated for extended periods on roads and other hard surfaces. Because of the nature of the campaign, the extensive zone of division supply responsibility, the heavy rainfall, the extremely rough and almost impassable terrain, and the limited road network, Army officials constantly called for more adequate quantities. The commanding general of one infantry division asserted that 200 to 225 M-29C's would be desirable for a division operating in similar terrain.

In some cases, reports pointed to the virtual freedom of the M-29C from failure and breakdown, and one division stated that with 108 units distributed throughout its medical, communications, and transportation groups and seldom at rest, never were more than five vehicles laid up for repairs at any one time. In other cases, it was reported that the Weasel suffered from delicate mechanical construction which required extreme care in operation and close first echelon maintenance, with excessive track failure noted after about 450 to 500 miles. In still others, it was reported that Weasels were often inoperative for excessive periods because of the lack of spare parts.

The Weasel was used to greatest advantage in the later campaigns, culminating in Okinawa. Drivers and maintenance personnel improved the performance of the M-29C by developing numerous field expedients, such as getting across extremely soft, muddy obstacles by going in reverse, and folding up the track aprons to prevent damage or fouling when crossing rough or stony ground or swamp land. In a few instances, operators obtained maximum performance by discovering for themselves the wisdom of following the manufacturer's instructions, notably using the lowest speed to cross very soft ground.

As with other vehicles used in the tropics, the M-29C was criticized for inefficient cooling and excessive corrosion, and—as with other vehicles—the Weasel was improved by field changes developed in general engine and anti-corrosion research.

Track failure was reported as the most serious failure of all models of the Weasel. These failures, as reported from the field, led to intensive research and development which resulted in improved track design and construction, as well as instructions to limit

the use of the Weasel on hard surfaces. Track life was consequently extended considerably beyond the early 1,000-mile mark, and in such later operations as the resurvey of the Alcan and Norman Wells highways in Alaska and Canada during the winter of 1944–45, tracks survived more than 3,000 miles without failure.

5.6 PRODUCTION SUMMARY

The performance of the Weasel, its ability to operate in mud, swamps, paddy fields, marshes, snow, shallow and deep water, and on turf and hard roads, and its value in transporting men and supplies under conditions where no other vehicle could operate all resulted in a total production of approximately 12,000 units by the end of the war, including about 750 T-15's, 3,000 M-29's, and 8,000 M-29C's. Plans for invasion of the Japanese home islands, the China coast, and other enemy-occupied territories included the production of about 10,000 additional M-29C's, which were on order on the date of Japanese surrender.

5.7 CONCLUSIONS AND RECOMMENDATIONS

It appears that there will be a continuing need for amphibious vehicles able to traverse snow, mud, sand, and hard ground, and to operate in deep water. For the development of such vehicles, the following recommendations are offered:

1. Development of the Weasel-type vehicle should be continued in order to develop both a small vehicle for reconnaissance work and a much larger vehicle, with a payload capacity of approximately 1½ tons, for cargo carrying.

2. The production designs of the T-15, M-29, and M-29C vehicles and their resultant highly satisfactory performance characteristics in soft terrain were achieved by construction and by quantitative tests of many variations in the several related units of the suspension and track system. Because of the urgency of the program, there was not time for a complete quantitative evaluation of the test results. It is believed certain that some of the features of construction are fundamental factors in the performance of vehicles with low unit ground pressure, and it is believed desirable that these features should be more carefully examined. A long-range research program should be instituted for their thorough investigation and for the determination of fundamental equations for use in future designs of the vehicle type, regardless of size. Major emphasis in such a program should be placed on such factors as length-width ratios of tracks and track plates, heights of grousers, diameter and spacing of bogie wheels, angles of approach and departure, effect of ground clearance, finishes for tracks and underbodies to prevent sticking of ice and mud, and prevention of excessive accumulation of foreign matter in the suspension parts.

FIGURE 78. United States Marines on Okinawa string telephone wire with aid of M-29C Weasel.

3. Attention should be paid to facilitating loading and unloading the vehicles, particularly the M-29 and M-29C Weasel, increasing their maneuverability while afloat, and increasing water speed. It appears that the incorporation of a propeller for water propulsion is not desirable, and studies should therefore be continued in an attempt to increase water speed from track propulsion and to increase ease of steering.

4. The hull of the present M-29C should be redesigned to reduce water resistance. At the same time the hull should be made in one piece instead of the three used in the current M-29C hull model, in order to reduce the weight materially without reducing the strength, and studies should be conducted on the proper angles of approach and departure for both the hull and the track.

5. Further studies should be undertaken to reduce the weight and ground pressure of the vehicle.

6. If the vehicle is to be used in any kind of surf it

will be necessary to increase the freeboard, waterproof the engine, and add power-driven bilge pumps.

7. A lubrication system should be designed to reduce the number of grease fittings in the bogie wheels and other suspension parts which require frequent attention, especially after water operation. In the current models, there are 58 such fittings. A system which would eliminate some of these or, perhaps, reduce the entire setup to a two-shot system would greatly reduce the driver's responsibility during combat.

8. Further studies, including the use of a torque converter, should be made to improve transmission life.

Chapter 6

AMPHIBIOUS GUN MOTOR CARRIAGE

Summary

An amphibious combat vehicle,[a] based on the standard M-18 gun carriage, was developed for use in landing operations. It is self-propelled, using its own tracks for water propulsion, and can fire either ashore or afloat. Three different models were designed and studied.

6.1 THE PROBLEM

Late in 1943, at the request of the U. S. Army Ordnance Department, a study was under way on the conversion of the M-18 "Hell Cat" 76-mm gun motor carriage (Figure 1) into an amphibious vehicle. Instead of merely fitting pontons to the existing gun carriage, modifications were to be developed so that the M-18 would be actually amphibious. The modifications, however, were to be kept to a minimum, and the standard components and their arrangements in the carriage were to be retained wherever possible.[b]

6.2 PROCEDURE

In order to facilitate production and repair, it was decided to use the M-18 engine, power train, suspension, turret, and controls, all arranged as they are in the M-18 nonamphibious model. One pilot model (T-86) was designed to be track-propelled, a second (T-86E1) to be propelled by twin screw propellers.

The design development included a study of improved tracks for the T-86 to give maximum water speed and ease in steering. Low freeboard, resulting from attempts to reduce the profile height to a minimum, and the necessity of providing full ends in the amphibious hull introduced vision problems, and various vision cupolas, periscopes, and block arrangements were tested in an attempt to solve them. Since steering by track was found to be unsatisfactory, cable-controlled rudders were added, and were found effective in both the T-86 and the T-86E1. Two air inlets were provided, one the conventional deck grill placed behind the turret, and the other through the turret cover to take all cooling air. Various types of cooling air exhaust stacks were tried. Field kit waterproofing was used in the first two models, but was not found satisfactory.

At the conclusion of the design study and field tests, plans were begun for a third model, the T-87, which was to be the prototype of the production model and to contain many of the improvements developed during this study.[5]

6.3 RESULTS

6.3.1 Model T-86

The track-propelled T-86 is shown in Figures 2 and 3. It is 351 inches long, 122 inches wide, and 135 inches high, with a ground clearance of 14¼ inches. Mounting a 76-mm gun and fully equipped, it weighs 45,000 pounds and has provisions for a five-man crew. The track is 21 inches wide, giving a ground contact

[a] Project OD-95.

[b] This investigation was conducted by Sparkman & Stephens, Inc., New York, N. Y., under OSRD contract OEMsr-151.

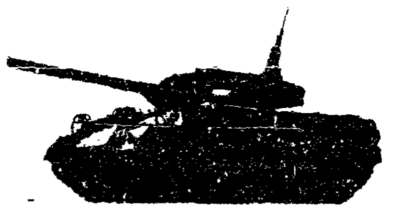


Figure 1. M-18 "Hell Cat" 76-mm gun motor carriage, parent vehicle for conversion.

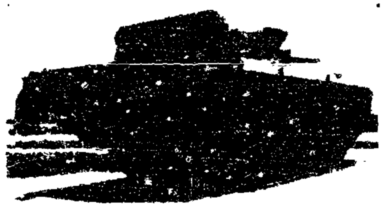


Figure 2. Side and rear view of pilot model T-86 amphibious gun motor carriage.

FIGURE 3. Side view of pilot model, T-86 amphibious gun motor carriage, showing side track skirting.

area at 4-inch penetration of 5,680 square inches and a unit ground pressure of 7.92. (See Table 1.)

TABLE 1. Comparison of Amphibious Gun Carriage Models.

	T-86	T-86E1	T-87
Water propulsion	Tracks	Propellers	Tracks
Over-all hull length in inches	351	351	321
Over-all hull width in inches	122	122	122
Height in inches	115	115	115
Weight in pounds	45,000	46,000	45,000
Track width in inches	21	21	21
Length of track on ground in inches	117	117	117
Tread in inches	95	95	95
Ground contact area in square inches	5,680	5,680	5,680
Unit ground pressure for 1 inch penetration (psi)	7.9	8.2	7.9
Ground clearance in inches	14	14	14
Angle of approach in degrees	31	31	31
Angle of departure in degrees	35	38	40
Maximum speed on land (mph)	45	45	45
Maximum speed in water (mph)	5.2	6.2	5.4
Grade ability in per cent	60	60	60
Horsepower per ton load	15.5	17.4	17.8

Its maximum speed is 45 mph on land and 5.2 mph in water, its cruising range is 150 miles on land and 80 miles in water, and it can be operated in a 12- to 16-foot surf.

In sea trials at Fort Ord, California, and Rehobeth Beach, Delaware, maneuverability and control were both satisfactory, and pitching and rolling were not severe enough to interfere with the comfort and safety of the crew. Except for small seal leaks, the crew and equipment were satisfactorily protected from waves and splash. The vehicle was run through surf ranging in height from 8 to 10 feet without serious diving or pitching. Performance in sand and on beaches was considered satisfactory, and the vehicle was able to land on the beach from the water at all points in the test areas.

Operation both in water and on land was improved by adding a third steering station just forward of the turret, cutting off the forward corners of the deck trunk, installing a vision block in both corners, and substituting a vision block for the forward periscope on the driver's side.

In one firing test, the vehicle opened fire at 1,500 yards and ran in to 800 yards, firing about 20 rounds. The accuracy was extremely poor, with all but the first shot going high. In another test, the vehicle opened fire at 2,800 yards and hit the target with four shots. Military observers indicated that the difference in these results was due to the difference in experience of the gun crews.

6.3.2 Model T-86E1

The propeller-equipped T-86E1, as shown in Figures 4 to 6, differs from the T-86 in having a total gross weight of 46,000 pounds, a unit ground pressure of 8.22 psi, a maximum speed of 6.2 mph in water, and a cruising range of 150 to 175 miles on land and 60 to 85 miles in water.

FIGURE 4. Side view of pilot model T-86E1 amphibious gun motor carriage.

FIGURE 5. Twin propellers on T-86E1 (Modification 1) amphibious gun motor carriage.

FIGURE 6. T-86E1 amphibious gun motor carriage afloat.

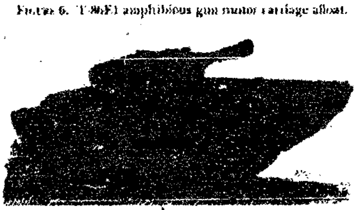


FIGURE 7. Pilot model of T-87 amphibious gun motor carriage.

6.2.3 Model T-87

Although the addition of propellers to the gun carriage increases the speed and the cruising range of the vehicle, the added equipment increases the total weight to 46,000 pounds. Accordingly, the prototype model T-87, shown in Figures 7 and 8, was designed to meet the specification of 45,000 pounds. Driven by tracks like the T-86, it differs from the former in having a hull length of only about 27 feet, factory waterproofing, and different armament, including a 105-mm howitzer, twin .30-caliber machine guns, and four automatic pistols. In water, its maximum speed is expected to be 5.4 mph and its cruising range 40 miles.

Design work on this model was started under NDRC, but final design and construction was done under the Development Branch, OCO(D).

Another design was completed as the result of a study of a larger amphibian built from standard components but not using a standard chassis as a basis. Intended to incorporate desirable features without concern for the time limitation in building pilot models, it follows the recommended trend in new amphibious tank design. The rear drive permits the turret to be moved forward. A sixth bogie is added to increase ground contact area and decrease unit ground pressure.

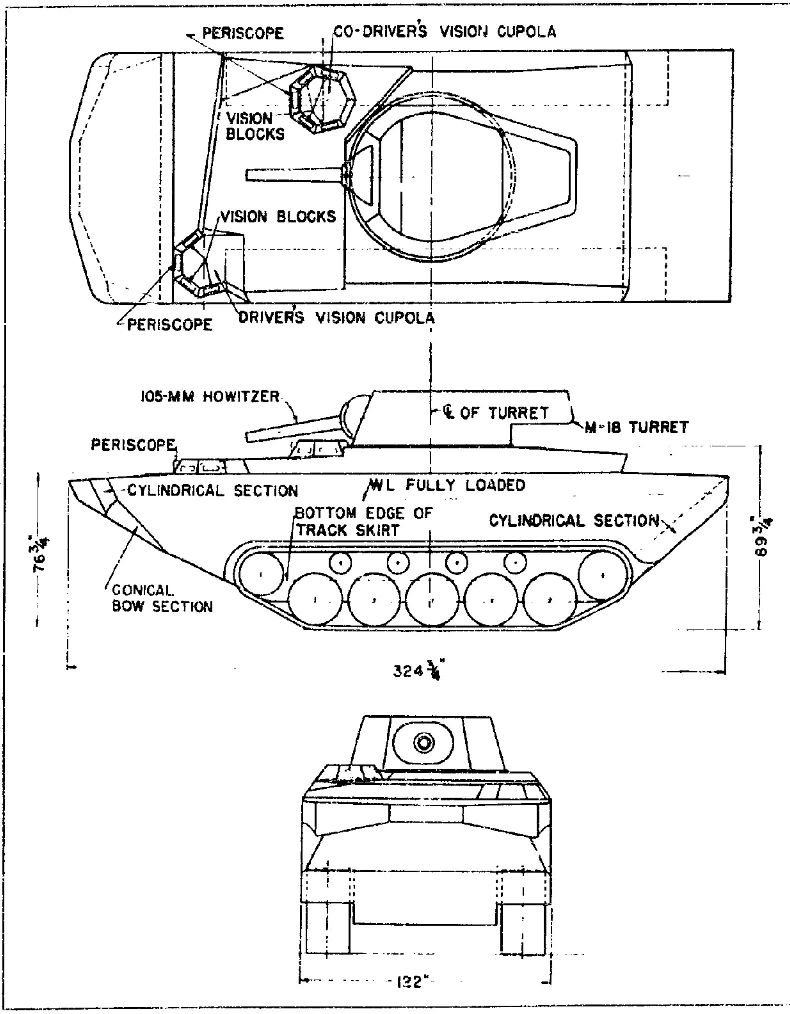


FIGURE 8. Diagram of T-87 amphibious gun motor carriage.

Chapter 7

PADDY VEHICLE

Summary

A LIGHT amphibious cargo carrier with a low unit ground pressure was designed for use in rice paddies and similar water-covered areas.[a] Based on the T-39 light tractor, a pilot model of this paddy vehicle was constructed for field tests under the Ordnance Department.

7.1 THE PROBLEM

In answer to a need expressed by the U. S. Army Ordnance Department, a study was initiated in September 1944 on the conversion of available track-laying vehicles into light amphibious cargo carriers.[b]

7.2 PROCEDURE

A survey and preliminary analysis was made of all available vehicles and components, together with experimental models undergoing tests or still on the drawing boards. From this analysis, it appeared that the most promising vehicles which might be used as a basis for the new paddy vehicle were the T-16 universal carrier, the T-9 light tractor, the T-9 light tank, the T-39 light tractor, and the power train of the M-3 or M-5 light tank.

Further study showed that an amphibian based on the T-16 universal carrier would have the advantage of light weight and low unit ground pressure, but would require considerable rearrangement of the power train. The amphibian would closely resemble the Weasel light cargo carrier but would have a higher rated payload and greater horsepower.

A carrier based on the T-9 light tractor would be promising in payload and power, but a complete rearrangement of components would be needed and a new suspension would have to be designed to accommodate a wider track.

The use of the T-9 light tank was considered at first but rejected because it was not then in production and would require many changes in the conversion.

A vehicle based on the M-3 or M-5 light tank power train would have high rated payload, high horsepower per ton, and reliable, proved components. On the other hand, it would also have high gross weight, and its components would have to be completely rearranged.

From these considerations, it was decided to proceed with an amphibian based on the T-39 light tractor (Figures 1 and 2). It was expected that such a vehicle would require only minor changes in arrangement of components. Although its horsepower would be low and its track was unproved, it would have high payload, low ground pressure, and a reliable

[a] Project OD 95.

[b] This investigation was conducted by Sparkman & Stephens, Inc., New York, N.Y., under OSRD contract OEMsr-151.

FIGURE 1. Front and side view of T-39 light tractor, parent vehicle for conversion.

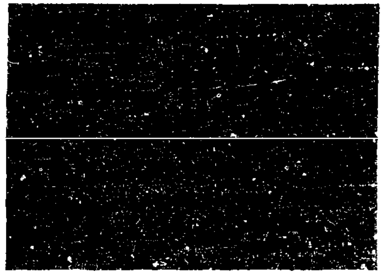


FIGURE 2. Top and side view of T-39 light tractor.

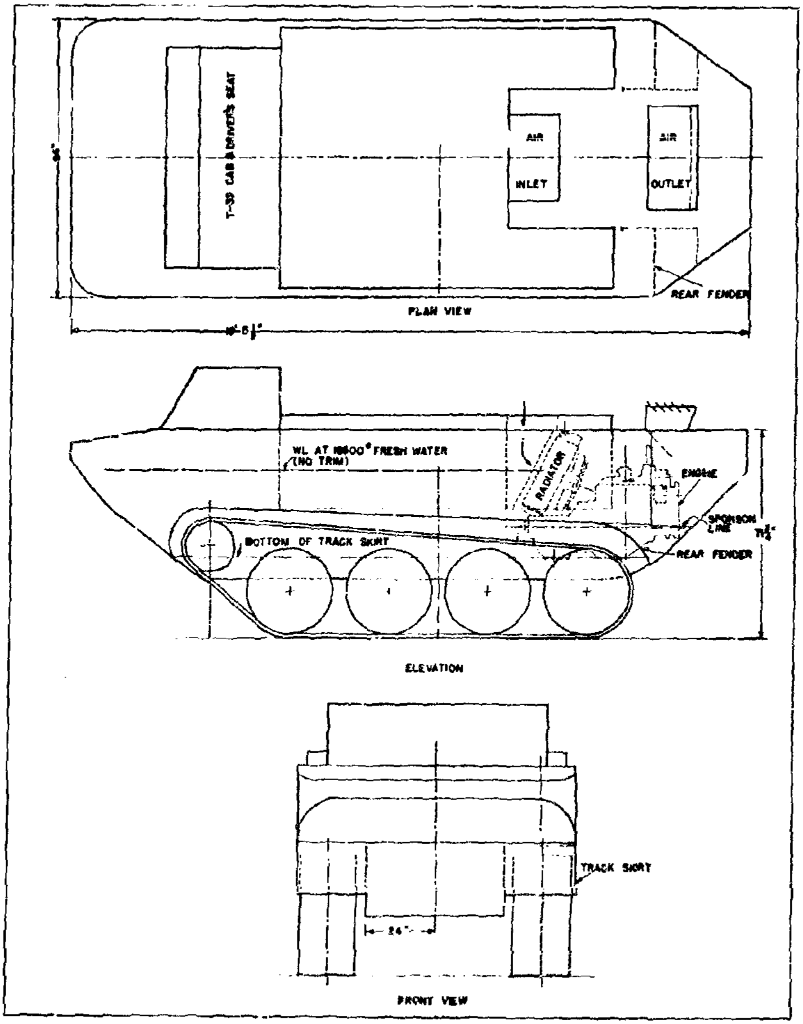


FIGURE 4. Diagram of T-31 paddy vehicle.

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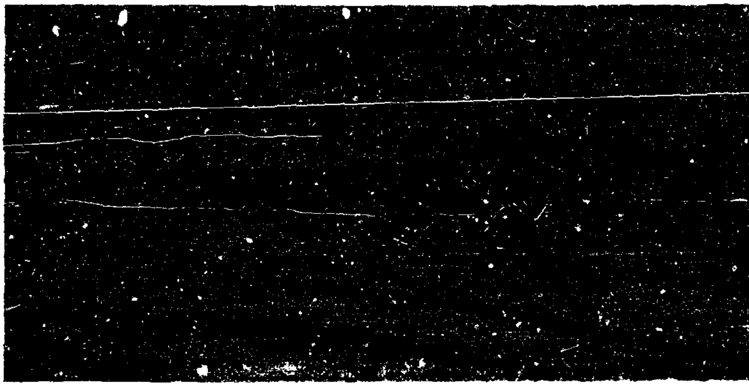

FIGURE 4. Side view of T-34 paddy vehicle, showing side track skirting.

power train. These advantages were thought to be of considerable value.

7.3 RESULTS

Design work was begun under the National Defense Research Committee [NDRC], with final design and construction undertaken under the Development Branch, Office of Chief of Ordnance, Detroit.

The design of the amphibian as converted from the T-39 is shown in Figure 3, with the pilot model[b] shown in Figures 4 and 5.[c]

The paddy vehicle is 19 feet 4 inches long, 8 feet wide, and 6 feet high to the deck, with a track width of 19 inches and a unit ground pressure of 4.3 psi. Cargo volume is 120 cubic feet, the floor area being 55 square feet, and the payload 3,000 pounds. The weight light is 14,000 pounds.

Later, after the termination of the investigation under NDRC, field tests were conducted under the Ordnance Department. These showed that the maximum speed is 4.0 mph in water and 20.0 on land, the grade ability is 60 per cent, and the horsepower per ton is 12.8.

[c] Constructed by the Lima Locomotive Works, Inc., Lima, Ohio.

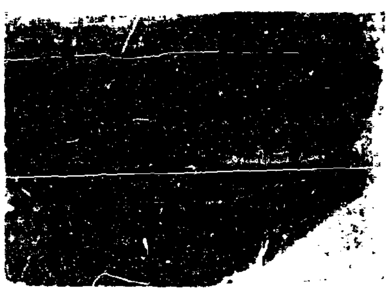

FIGURE 5. Rear view of T-34 paddy vehicle, showing skirting and rudders.

Chapter 8

PROPOSED AMPHIBIOUS VEHICLES

8.1 PELICAN

Summary

Under this project,[a] a survey was made of existing land vehicles and components available for use in large-wheeled and half-track amphibians to have a rated payload of 6 tons or more. Design and development extended only through drawings, calculations, and scale model tests. No full-size pilots were constructed.

8.1.1 The Problem

By July 1942, early work on the DUKW 2½-ton amphibian indicated that a larger vehicle was desirable, and a design study was consequently initiated for such a vehicle to be based on a standard land vehicle or its components.[b]

8.1.2 Procedure

As a basis for a wheeled amphibian with a 6-ton payload, several models were considered.

WHITE 6-TON 6x6 CHASSIS

Layouts were prepared and a scale model tested of a propeller-driven amphibian with a scow-type hull and wheel cutouts and tunnels similar to those in the DUKW.

The full-size model would be about 34 feet long and 8 feet wide, and would weigh 28,000 pounds light.

BROCKWAY 6-TON 6x6 CHASSIS

Two scale models were built and tested, the first having a DUKW-type hull and the second having a boat-type hull with appendages, as shown in Figure 1.

In full scale, each would be approximately 41 feet long and 10 feet wide and would weigh about 28,000 pounds unloaded.

CHEVROLET ARMORED CAR T-19 CHASSIS

Preliminary layouts were made of a 5-ton 6x6 vehicle and a 7-ton 8x8 amphibian (Figure 2) based on the T-19 chassis.

[a] Project OD 95.

[b] This investigation was conducted by Sparkman & Stephens, Inc., New York, N. Y., under OSRD contract OEMsr-151.

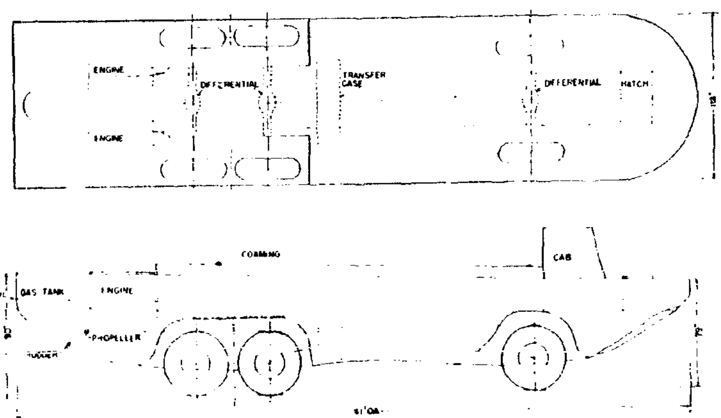

Figure 1. Plans of amphibian based on 6-ton 6x6 Brockway chassis.

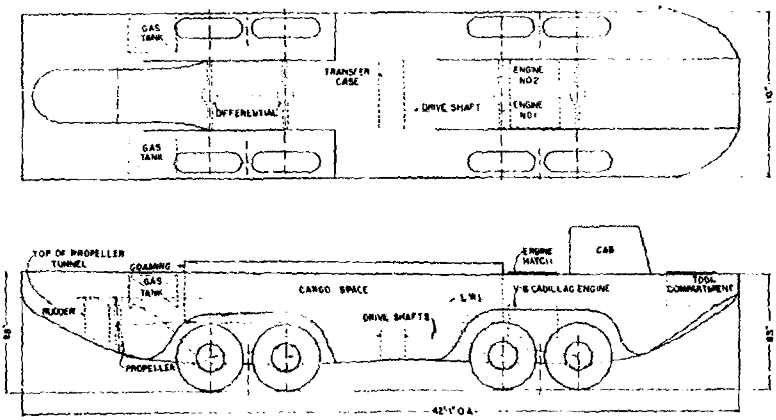

Figure 2. General arrangement of 7-ton, 8x8 amphibian using T-19 Chevrolet armored car components.

The 5-ton amphibian has approximately the same over-all dimensions and weight light as does the proposed Brockway conversion, while the 7-ton vehicle is proportionately larger. Decreased resistance was anticipated because the power train would permit complete housing of the differentials and drive shafts. This chassis would have the advantage of more power than the Brockway, but it is not standard and was not in production at the time of the investigation. The time involved in getting such a vehicle in production was judged to be too long, and further work on it was dropped.

These studies indicated that the preferred hull for wheeled cargo amphibians is essentially rectangular in section, with a scow bow, little or no dead rise, tunnels for all appendages, full scow stern, and maximum housing for all wheels.

Half-tracks

For payloads more than 6 tons, the disadvantages of wheeled vehicles become decisive. Study was therefore initiated on a series of half-track amphibians for payloads of from 2 to 25 tons. Calculations and layouts were made and some scale models tested.

Only brief consideration was given to a proposed amphibian based on the standard Army troop-carrying half-track, which would have a gross weight of about 19,000 pounds but a rated payload of only about 4,000 pounds.

Instead, major interest was devoted to a half-track amphibian based on the track and suspension of the medium tank. It was concluded that a practical half-track amphibian would require a completely new design. It would have to be appreciably larger than the DUKW and accordingly would have additional uses, such as ferrying a fully loaded 2½-ton truck in ship-to-shore operations. Since it was desirable to use existing equipment, the medium tank track and suspension apparently offered the best basis on which a new design might be started.

Four primary designs were prepared, one with two individually suspended front wheels and two-thirds of the medium tank track and suspension (Figure 3), one with four front turning wheels and two-thirds of the track and suspension (Figure 4), and two designs, each with four wheels and full track and suspension (Figures 5 and 6).

In each case both screw and Kirsten cycloidal propellers were studied. The proposed gross weights vary from 40,000 to 110,000 pounds, and the over-all lengths from 40 to 55 feet. The vehicles would be powered by two 220-hp Diesel or gasoline engines, and would incorporate a loading ramp to enable them to carry fully loaded trucks or tanks.

Model tests showed that, in general, the front wheels account for about 6 per cent of the total resistance, the tracks for about 9 per cent, the front wheel cutout for about 10 per cent, the track cutout for

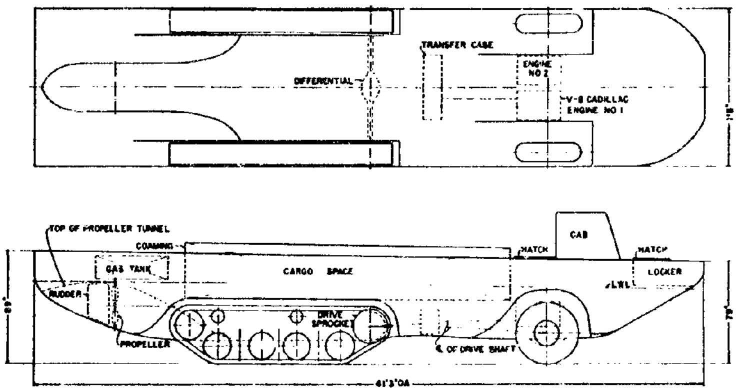

Figure 3. Plans for proposed Pelican with two front wheels and two-thirds of medium tank track.

about 15 per cent, and the combination of wheels and cutouts alone for about 50 per cent. It is apparent, therefore, that the pure hull efficiency is reduced by the necessity for housing wheels and other appendages, and that the actual and incidental increase in resistance due to wheels, wheel suspension, and driving equipment is at least as great as the resistance of a comparable boat.

The lowest resistance per ton for the same speed-length ratio of all models tested is given by the vehicle with two front, individually suspended wheels and full medium tank track and suspension. A full-

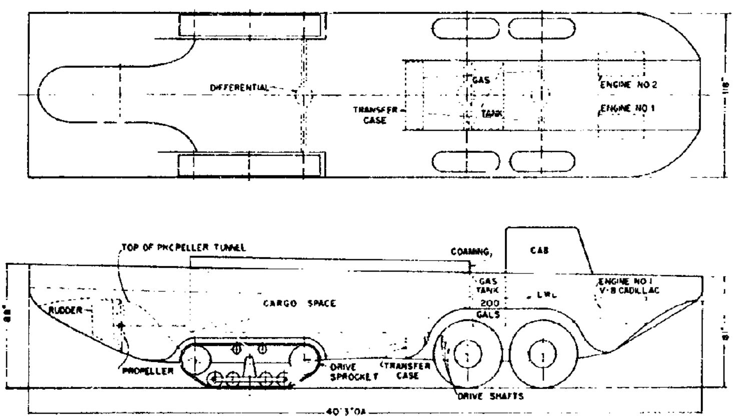

Figure 4. Plans for proposed Pelican with four front wheels and two thirds of medium tank track.

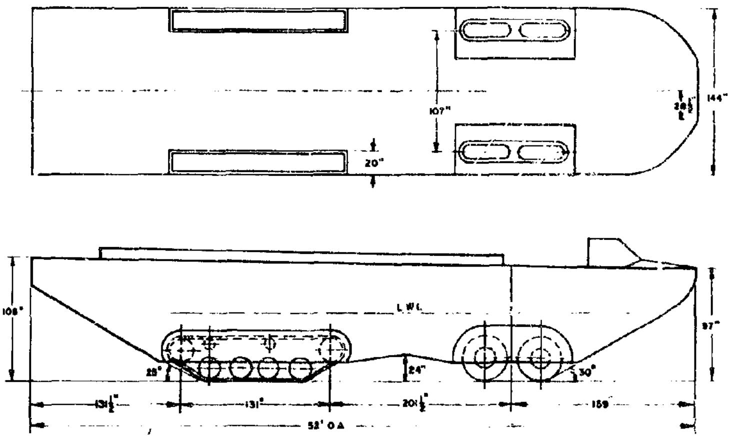

FIGURE 5. Plans for proposed Pelican with four front wheels and full medium tank track.

scale unit of this type (Figure 7) would have an over-all length of 51 feet and a width of 144 inches. With 400 hp to drive two cycloidal propellers, it would have a speed of 8 mph in water. It would weigh 40,000 pounds light and 80,000 pounds loaded. It would have a stern ramp and sufficient cargo space to take a fully loaded 6-ton 6x6 truck.

8.1.5 Conclusions

Although none of the units investigated in this study was carried to completion, the information obtained was applied to advantage in the study of other amphibious vehicles designed under Division 12[4] and should be of value to any future program for the design of amphibious cargo carriers.

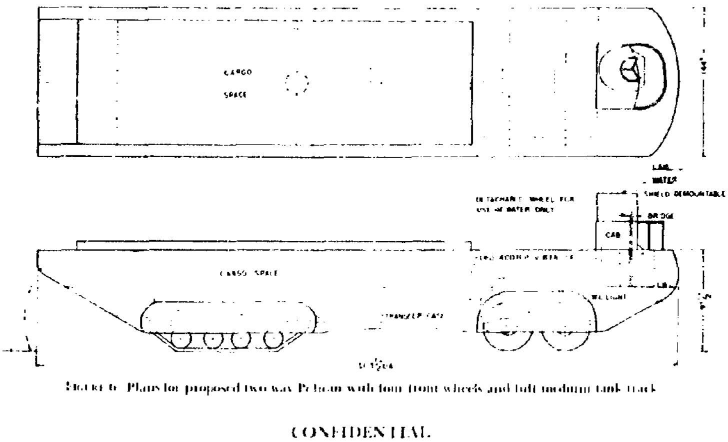

FIGURE 6. Plans for proposed two way Pelican with four front wheels and full medium tank track.

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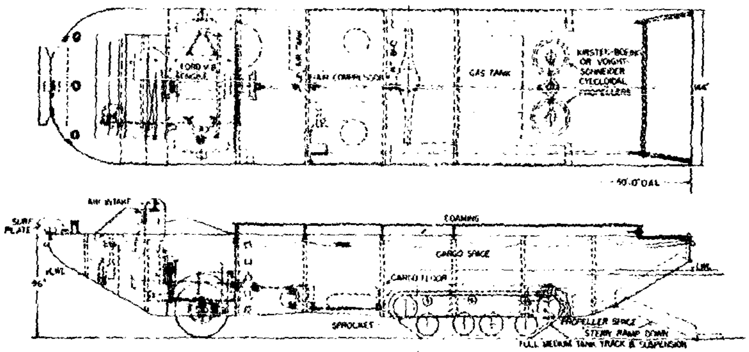


FIGURE 7. Plans for final proposed Pelican with two front wheels and full medium tank track.

8.2 FIFTEEN-TON, ¾-TRACK AMPHIBIOUS CARGO CARRIER

Summary

Designs have been developed for a 15-ton, ¾-track amphibious vehicle to carry heavier loads and bigger vehicles than was previously possible. Drawings and model tests were completed, but no pilot model was built.

8.2.1 The Problem

At the request of the U. S. Army Ordnance Department, design work was undertaken in May 1944 on a large ¾-track carrier for ship-to-shore operations.*

* This investigation was conducted by Sparkman & Stephens, Inc., New York, N.Y., under OSRD contract OEMsr-151, in cooperation with the Development Branch of the Office of Chief of Ordnance, Detroit, Mich.

8.2.2 Procedure

A study of existing U. S. Army half-tracks and captured German ¾-tracks, together with conferences with Ordnance Department representatives, led to the design shown in Figures 8, 9, and 10. Later, in order to provide closer coupling of track and front wheels, a sixth bogie wheel was added on each side, as shown in Figure 11. This also reduced the unit ground pressure by increasing track ground contact length and ground contact area.

Individual suspension or a single transverse leaf spring suspension for the front wheels was recommended. This provides for a minimum of hull movement over uneven terrain. Size 14:00 by 24 tires were selected to improve mud performance. An intermittent front wheel drive was specified to assist in exits from the water by traction and to improve steering

FIGURE 8. Side view of model of proposed 15-ton, ¾-track amphibious cargo carrier.

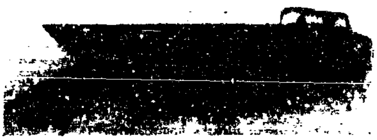


FIGURE 9. Model of proposed 15-ton, [illegible] track amphibious cargo carrier showing stern ramp down for unloading.

control in surf or up steep banks or beaches. A 21-inch steel track as developed for the T-87 amphibious gun motor carriage was specified because its width and low weight contribute to low unit ground pressure and improved performance. Further track development was recommended. Torsion bar, volute spring-stopped suspension was specified especially because these standard components were already in production.

The M-18 power equipment was specified because of its availability and proved worth. An hydraulic-type transmission was recommended to prevent digging in water exits by gradual application of increased torque as required.

A ramp was provided to assist loading and unloading of cargo and vehicles to be carried in the cargo space. Sufficient space was indicated to permit loading and transport of Army vehicles up to and including light tanks.

8.2.3 Results

The hull design as shown in Figure 10 was later modified to permit the vehicle to enter an LST [Landing Ship, Tank] ramp from the water. Wheels and tracks were housed in cutouts fitted with outside cover plates. A permanent cover plate and a removal plate were specified. A rectangular hull in cross section with no dead rise provides maximum buoyancy for given dimensions. Cutout cover plates for the tracks should be hinged to permit track servicing. Decking at the stern is necessary for protection in rough water and surf and in steep exits from water.

A power take-off for a twin screw propeller drive is shown, with the propellers and rudder housed in a tunnel protected by the hull and the track. In case the propellers are damaged, emergency propulsion can be obtained from the shrouded track. A modified Kort Nozzle propeller shrouding[d] was incorporated.

The proposed vehicle, as shown in Figure 11, would have a net weight of 40,000 pounds and a payload of 30,000. Its estimated maximum land speed is 35 mph.

[d] Designed by the Dravo Corporation, Pittsburgh, Pa.

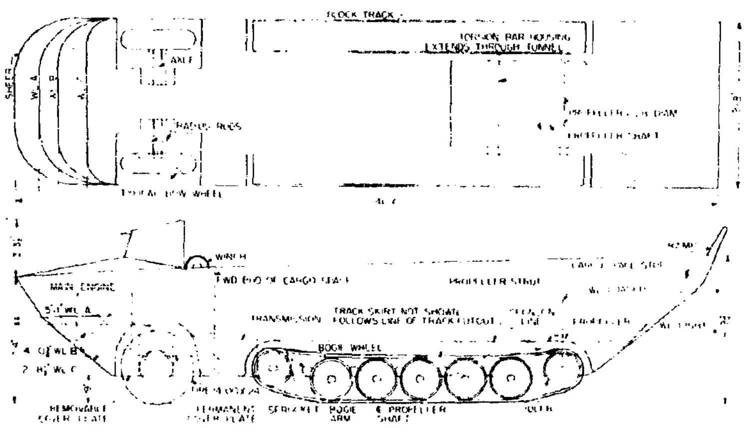


FIGURE 10. Plan of proposed 15-ton [illegible] track amphibious cargo carrier.

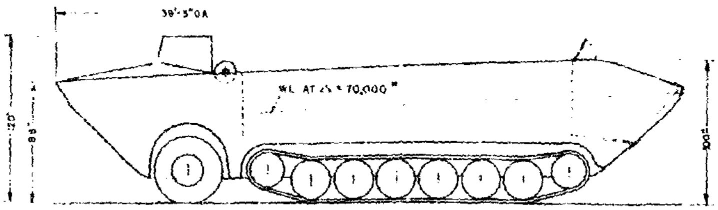


FIGURE 11. Plan for proposed modified 15 ton, ¾ track amphibious cargo carrier.

its water speed 8 mph, its land cruising range 200 miles, and its grade ability 60 per cent.[a]

8.3 AMPHIBIOUS TRAILERS

Summary

Several trailers were designed for use with the DUKW and the Pelican, and one 2½-ton, two-wheel experimental unit was built and tested.

8.3.1 The Problem

In order to increase the carrying capacity of proposed amphibious vehicles, a design study was instituted on amphibious trailers which could be used with the DUKW or with one of the types of Pelican under consideration.[b]

8.3.2 Procedure

Two designs were developed for the DUKW, one a 1-ton and the other a 2½-ton trailer, each with two wheels. Two others were developed for the Pelican, one a 10-ton and the other a 20-ton trailer, each with four wheels.

8.3.3 Results

An experimental pilot model of a DUKW trailer was constructed as shown in Figure 12.[c] Its over-all length is 176 inches, its width 96 inches, its height to deck 65 inches, and its weight light 2,000 pounds. Tests showed that this trailer is unsuitable for use in the surf and that it decreases the maximum water speed of the tractor DUKW by about 2 mph. While the trailer offers a convenient method for increasing the payload of the DUKW (Figure 13), the disadvantages were sufficient to halt further development.

The investigation showed that the wheels and suspension must be housed to reduce water drag, and that the trailer must be designed to act as an addition to the tractor hull. Separation from the tractor allows an independent wave system to form and tends to increase greatly the total surface wave-making resistance of the combination.[1]

[c] Built by the Yellow Truck & Coach Co., Pontiac, Mich.

FIGURE 12. 2½-ton amphibious trailer attached to DUKW for land operations.

FIGURE 13. Loaded 2½-ton amphibious trailer towing astern of loaded DUKW.

Chapter 9

AMPHIBIOUS DEVICES

9.1 VEHICLE FLOTATION DEVICES

Summary

Various devices for ferrying vehicles or temporarily converting them for amphibious operation were studied intermittently from April 1941 to early in 1945. In many cases, only calculations and design sketches were completed; in others, the work progressed as far as scale model tests; and in still others, pilot models were built and tested, and a few devices went into production. These latter included the Ritchie T-6 and T-7 rigid pontons for medium and light tanks, respectively, which were developed by the *Ordnance Department* with members of *Division 12* serving as design consultants. The T-6 device was used successfully in landing operations at Okinawa.

9.1.1 The Problem

A study of methods to land tanks under conditions in which landing boats could not be used was started in April 1941.[a] An early exchange of data with British workers led to particular emphasis on designs of rigid plywood or metal side pontons, but these were temporarily dropped without tests and major attention was given to the use of the DUKW as a ferrying vehicle.

Effective "dry ferry" and "wet ferry" devices were developed for enabling the DUKW to carry vehicles up to the weight of the medium tank.[b] These devices were never exploited beyond the experimental stage since better means for doing the same thing were developed by the Armed Services. The investigation of flotation was later redirected to flotation devices as well as flotation vehicles, and emphasis was again placed on ponton studies and similar problems. Further impetus to this approach was given by the successful submerged track propulsion tests made on the Weasel in the summer of 1943,[c] which, with later tests, clearly indicated the potentialities of water propulsion by means of fully submerged standard land tracks.

9.1.2 Procedure

The loosely coordinated studies of Division 12 and OCOD were integrated under the "Ritchie Project" in January 1944, and Division 12 was requested to act throughout this program as a consultant to the Ordnance Department. Under this project, several devices for tank flotation were built and tested, including the following:

1. The *Hale Device*, with collapsible side pontons inflated by tank engine exhaust gas, the entire unit propelled by screw propellers driven off the rear idlers.

2. The *Engineer Ponton Device*, with the tank suspended between two pontons in a wet ferry and propelled by outboard motors.

[a] This investigation was conducted by Sparkman & Stephens, Inc., New York, N. Y., under OSRD contract OEMsr-151.

[b] See Section 3.6.2.

[c] See page 171.

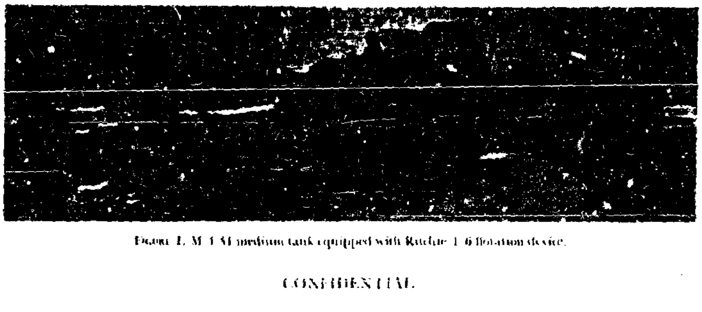


Figure 1. M 4 A1 medium tank equipped with Ritchie T-6 flotation device.

Figure 2. Front view of M-4 A1 medium tank equipped with Ritchie T-6 flotation device.

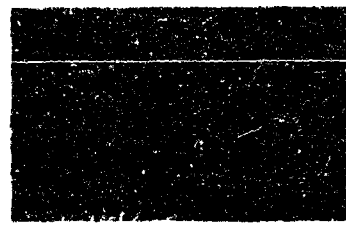


Figure 3. Pontons of Ritchie T-6 flotation device are secured with removable pins.

3. *DD* and *Yagow Devices*, consisting of collapsible, vertical, canvas tank hull extensions, the unit propelled by screw propellers driven off the track suspension.

4. *BB* or *Ritchie T-6* and *Ritchie T-7 Devices*, described below.

5. The *Blankenship Device*, using detachable, inflatable bags to provide the necessary additional buoyancy.

6. *DUKW* ferrying devices, described elsewhere.[b]

9.1.3 Results

THE RITCHIE T-6 FLOTATION DEVICE.

Figure 1 shows the Ritchie T-6 device fitted to the M-4 A1 medium tank. In this installation, two large welded steel pontons are attached by pins to the forward end of the tank (Figures 2 and 3), two other large units are attached to the aft end, and four smaller units are attached on each side. The unit is propelled in the water by its shrouded fully submerged tracks. Tests conducted at Tacony, Pennsylvania, showed that this model can travel at about 4.2 mph in water (Figure 4). This speed can be increased

Figure 4. Ritchie T-6 flotation device afloat.

to nearly 7 mph by the use of special grousers, but these make land maneuvering more difficult.

The T-6 device, slightly modified and supplied with equipment to jettison the pontons, went into production for possible use in the invasion of Normandy. Actually, however, it was first used in combat in the invasion of Okinawa, when 20 of these devices were employed by the Marine Corps, making it possible to place 20 tanks on the beach without the need of special landing boats. The pontons were detached as soon as the tanks touched land, allowing the units to go into action immediately without exposing their crews to direct enemy fire.

THE RITCHIE T-7 FLOTATION DEVICE.

The Ritchie T-7 device, as illustrated by the scale

Figure 5. Scale model of Ritchie T-7 flotation device attached to M-18 gun motor carriage.

Figure 6. Experimental installation of Ritchie T-7 flotation device on M-18 gun motor carriage.

model in Figure 5, consists of only two pontons, one attached to the forward end of the M-18 gun carriage and one attached to the after end. The tracks are shrouded for higher propulsive efficiencies in the water. At the completion of the model tests, a full-size unit was constructed and fitted to the M-18 carriage (Figure 6). In field trials, the maximum speed of this unit in water was found to be from 4.2 to 4.8 mph. Similar devices were applied to the M-24 and M-5 A1 light tanks.

Light Tank Flotation Devices

Several methods and types of equipment for floating different light tank models were studied between April 1942 and January 1945. Among these were vertical hull extensions, side and end pontons, rigid and collapsible floats, and the use of amphibious vehicles or boats to make up the deficient buoyancy. Experiments with the Straussler collapsible hull device were considered to be unsuccessful. The recommended types are the end float devices with either rigid pontons (Figure 5) or collapsible pontons (Figure 7).

The pontons in the latter case would consist of inflatable, rubberized fabric bags housed in metal covers which would unfold in the water and protect the bags in the floating and stowed position. A rotary vane pump would be used to inflate the bags through individual air lines. Since the front and the rear pontons would each be composed of three bag sections, the failure of one bag or its destruction by gunfire would not result in total failure of the flotation. In operating this device, the forward ponton would first be swung from its stowed position aft and its beam clamped into a beam lock. Both forward and aft bags would then be inflated, and the vehicle would be ready to enter the water. When the tank leaves the

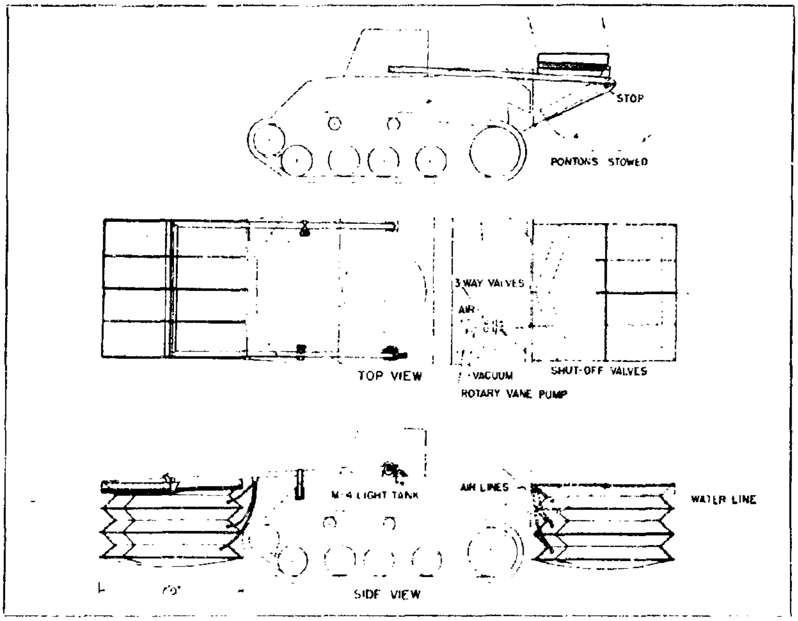


Figure 7. Diagram of collapsible fabric pontons designed for M-4 light tank

water, the beam would be released from the beam lock, the pontons deflated, and the forward ponton swung aft. As the forward ponton falls into its final position, it would hit a stop and force the aft ponton into its final stowed position.[3]

RIGID PONTONS FOR THE JEEP

During the early development of the amphibious jeep, tests[a] were conducted simultaneously on rigid pontons[b] to be attached to the sides of the standard GP ¼-ton truck. These pontons swing down into the water from a stowed position and are to float the vehicle at a water line about 5 inches below the wheel hub center. Propulsion would be obtained from an outboard-drive screw propeller driven by a power take-off from the truck engine. Towing tank tests with scale models, however, showed that although these pontons permit the vehicle to move slightly faster in water than can the amphibious jeep, the difference is insufficient to outweigh the disadvantages of coping with large, portable, rigid pontons.[1]

COLLAPSIBLE PONTONS FOR THE JEEP

At the request of the U. S. Army Ordnance Department, attention was directed toward the design of detachable, collapsible pontons which could be used for traversing deep water. Figure 8 illustrates a method recommended for the jeep. Special waterproofing treatment would have to be given to the vehicle. No pilot model of this device was constructed.[4]

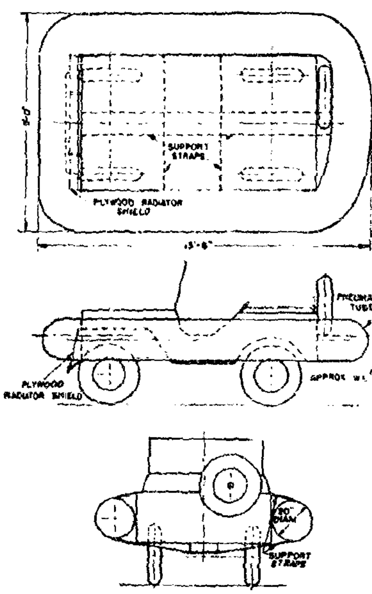


FIGURE 8. Diagram of collapsible ponton design for standard ¼-ton, 4×4 jeep.

9.1.4 Conclusions

With the development of waterproofing methods for standard Army vehicles, the value of the collapsible ponton in ferrying operations is potentially increased. Even though no satisfactory inflatable ponton was developed in this study, there does not appear to be any insurmountable design problem. It is therefore proposed that the investigation be continued on the development of pontons which can be stowed and carried by the vehicles and which can be attached and inflated whenever desired. The vehicle should be able to use its own power to enter, leave, and travel in the water.

9.2 TRAILER HITCH

A special hitch developed for amphibious trailers has been constructed and shown in tests to reduce by 50 per cent the time required to connect the trailer to the tractor.

In January 1945, at the request of the U. S. Marine Corps, work began on the development of an amphibious trailer hitch which would simplify connecting the trailer to the tractor, such as an LVT or a DUKW, and improve the method of release.[a]

In February, the first model of the hitch was designed. It was so constructed that upon release the entire mechanism is separated from the tractor and retained by the trailer. Field trials showed that its use reduces by 50 per cent the time required for making the connection. Structural failures, however, developed during these trials under loads closely approaching the maximum likely to be applied. The design was consequently revised and the strength increased approximately three times. It is believed

[d] Constructed by James Cunningham, Son & Company, Rochester, N. Y.

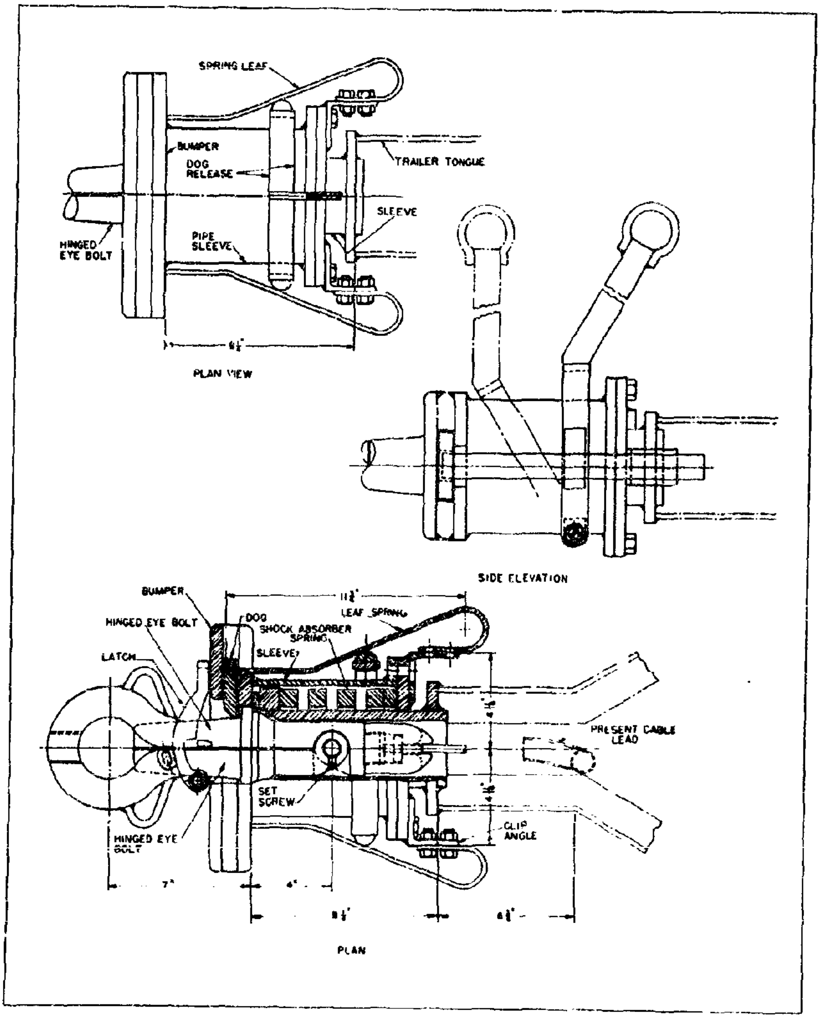


FIGURE 9. Plans for amphibious trailer hitch

that this modified structure (Figure 9) will operate satisfactorily.[7]

Although the use of this hitch with a trailer results in a loss of water speed—about 2¼ knots—this does not seriously affect its use in specific applications by the Marine Corps.

In cases where merchant vessels must literally jettison their cargo off the beach in order to avoid sudden attack, these cargoes can be picked up later in amphibious trailers without any great urgency.

9.3 SELF-PROPELLED AMPHIBIOUS DEMOLITION CHARGES[e]

A special type of bow attachment was designed to give high stability to a high-speed, rocket-propelled amphibious demolition charge. Only limited tests were conducted before the end of the war, and the attachment was not approved for production until after the war had ended.

As part of a larger program being conducted by Division 17 of NDRC,[f] a study was begun in March 1945 on the design of a special type of bow attachment to give high directional stability to a high-speed amphibious device. This attachment (Figure 10) was intended to simulate the shape of a typical V-bottom motorboat and to keep the amphibious device from heeling over and then veering in the direction of heel. The plan calls for bottom sections which can be developed and laid in with steel.[8]

Three of these bows were later built and attached to the high-speed, rocket-propelled amphibious demolition charge known as the Snake (Figure 11), and submitted for tests during the week of August 8, 1945 at the U. S. Naval Amphibious Training Base at Fort Pierce, Florida. In the first two tests with the device

[e] Project "Snake."
[f] Summary Technical Report, Division 17, Volume 1.

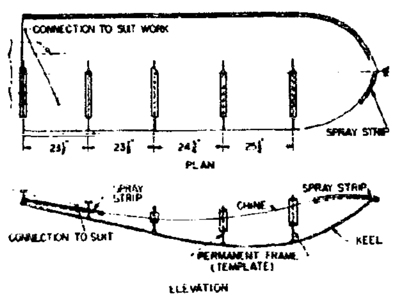


FIGURE 10. Plan for bow attachment for project Snake

FIGURE 11. Special bow attached to Snake.

FIGURE 12. Snake with special bow attachment ready for launching from LCM(3).

launched from an LCM(3) (Figure 12), the rockets were faulty and failed to move the Snakes. In the third test, the Snake was launched about 1,800 feet offshore, traveled in a straight line across the water, beached, plowed into a wall of Japanese scullies three deep, demolished the first, overturned the other two, and continued on for half its own length (Figure 13).

In another test, a Snake equipped with this bow landed 4 feet from the target, while units based on a U. S. Marine Corps design landed an average of 150 feet from the target.

Despite the success of these early tests, the bow design was not accepted for production and instead the Marine Corps model was adopted. The first units were scheduled to be shipped to the Pacific Theater at the end of August. Later, however, plans were changed and the boat-type bow was incorporated in the final design, but by that time the war had ended.

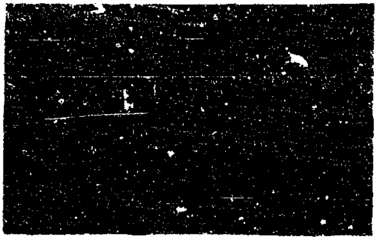


FIGURE 13. Snake with special bow attachment on beach at Fort Pierce, Florida, after offshore launching.

Chapter 10

AMPHIBIOUS STUDIES

10.1 TRACK PROPULSION IN THE LVT CARGO CARRIER[a]

Summary

Experimental towing tank tests were conducted on two models of the LVT cargo carrier, one with tracks completely submerged and the other with the return tracks out of the water. These studies, including measurements of resistance, self-propelled speed, self-propelled drawbar pull, and friction, showed that under the conditions of the investigation and with the track used the emerged track is superior.

10.1.1 The Problem

In November and December 1944, tests were conducted at the request of the Development Branch of the Office of Chief of Ordnance, Detroit, to determine the relative merits of emerged and submerged tracks for water propulsion of the LVT cargo carrier (Figure 1).[b]

10.1.2 Procedure

Two scale models[c] were supplied for these tests, LVT Model N-3 (Figure 2), which operates with the return tracks emerged from the water and closely duplicates the standard LVT (2) cargo carrier in production for the Navy, and LVT Model N-4 (Figure 3), which operates with the return tracks submerged. The two models have essentially the same hulls, with the same dimensions, tracks, suspension components, and drive. Model N-4 is equipped with track shrouding consisting of stern block, bowblock, and track skirt.

Several self-propelled speed runs corresponding to the available range of track speeds were made with each model, which was guided on a straight course by means of the towing tank carriage, a guide channel, and accelerator posts (Figures 4 and 5). Data for determining propulsive efficiency for each type of track were recorded. Stationary tests were run on both

[a] Project DD-95.

[b] This investigation was conducted at the Stevens Institute of Technology, Hoboken, N. J., under the supervision of Sparkman & Stephens, Inc., New York, N. Y., under OSRD contract OEMsr-151.

[c] Supplied by the Food Machinery Corporation, Calif.

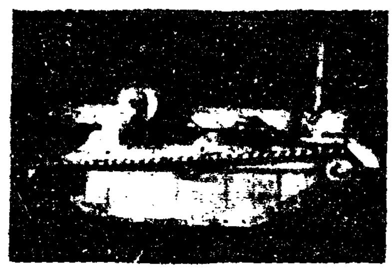


Figure 2. N-3 scale model of LVT for towing tank tests.

Figure 1. Stern view of LVT showing "controlled flow" track design.

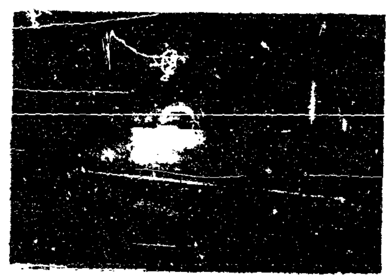


Figure 3. N-4 scale model of LVT on towing tank tests.

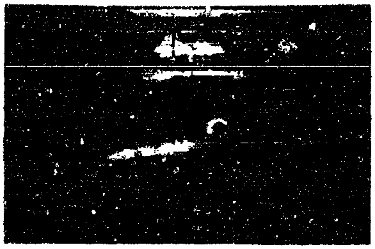


FIGURE 4. N-3 scale model of LVT showing upper track emerged and distinctive wave pattern.

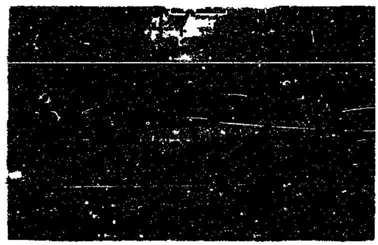


FIGURE 5. N-4 scale model of LVT showing completely submerged track.

models and the drawbar pull was measured at various points in the available track speed range.

Each model was towed at speeds ranging from 2.5 to 5 feet per second (equivalent to 4 to 8 mph in a full-size prototype) with track and drive stationary, and records were made of resistance.

10.1.3 Results

These tests showed that the resistance of the N-4 is about 5.5 per cent higher, and the self-propelled speed at any comparable horsepower and the drawbar pull are both less.

A comparison of the self-propelled speed of each model showed the N-3 gives a higher speed for the same net track horsepower, or requires lower horsepower for the same speed. This difference is appreciable; at a speed of 4 feet per second it amounts to 0.27 horsepower, or about 15 per cent less than the horsepower required by the N-4 to give the same speed. Correcting for difference in the resistance of the two models, however, indicates that about the same track speed is required to give the same thrust in each case.

At the time of these tests, the track design as shown in Figure 1 was found to be the most efficient of all tested under the auspices of the National Defense Research Committee [NDRC].

Under the conditions of these tests and for the particular track design used, the emerged track in Model N-3 is superior to the completely submerged track in Model N-4 for propulsion in water. These conclusions apply only to the track design tested, and the results do not necessarily apply to tracks that differ appreciably from this design.[2]

10.2 SUBMERGED TRACK PROPULSION

Summary

From a laboratory study of models and from field tests of various track-laying amphibians, it is apparent that in no case does the efficiency of track propulsion approach that which can be expected from screw propellers.

For optimum performance, if both the top and bottom tracks of the amphibian must be submerged during operations in water, the track should be shrouded with a full bow scoop, a medium skirt, and a stern scoop. The track should have grousers formed for effective movement of the water in the direction of track motion. The smallest clearance practicable should be provided between the upper tips of the return track and the underside of the sponson. Dimensions, suspension, track, power train, and all items except hull and weight distribution should be determined on the basis of land performance requirements.

The upper track should never operate at a distance less than 1 foot above or below the water surface.

In analysing submerged track propulsion, it should be noted that the action is not basically comparable to paddle wheel propulsion.

10.2.1 The Problem

Because of military requirements, many track-laying vehicles have been converted by one means or another into amphibians. In many cases, this conversion has resulted in totally submerging the tracks, which must be used for propulsion in water. In order to improve the performance of existing and proposed

vehicles of this type, an investigation was requested in the summer of 1943 by the Development Branch of the Office of Chief of Ordnance, Detroit, on amphibious cargo carriers, gun carriages, tank conversion equipment, and self propelled track-laying models.[d]

10.2.2 Procedure

Full-scale propulsion tests were conducted on the Weasel M-29C amphibious light cargo carrier,[e] the standard T-70 gun motor carriage equipped with simple track shrouding (Figure 6), the T-6 conversion equipment for the M-4 medium tank[f] and the T-7 conversion equipment for the M-18 gun motor carriage.[g] Drawbar and speed tests were conducted on these units as modified with different types of tracks, grousers, and shrouding.

For the self-propelled model studies, extended studies were conducted on a unit as shown in Figure 7, with an over-all length of 45½ inches, a width of 14½ inches, a weight of 104 pounds, suspension similar to that on the T-70, and a track driven by an electric motor mounted inside the hull.[h]

Measurements were made of the resistance of the model first with the tracks stationary and then with the tracks moving, of the speed of the model at different track speeds, and of the friction of the test setup. These were compared with drawbar pull tests made with the model stationary and connected to a dynamometer. To permit an evaluation of the factors underlying the results, these measurements were made with various modifications of (1) clearance between the underside of the sponson and the top of the return track, (2) bowblocks, (3) skirts and skirt holes, (4) stern arrangements, (5) operating water line, and (6) tracks (see Figure 8).

[d] This investigation was conducted by Sparkman & Stephens, Inc., New York, N.Y., under OSRD contract OEMsr-151.

[e] See Chapter 5 in this volume.

[f] See Chapter 9 in this volume.

[g] See Chapter 6 in this volume.

[h] These studies were conducted at the Webb Institute of Naval Architecture, New York, N. Y., and the Stevens Experimental Towing Tank, Hoboken, N. J.

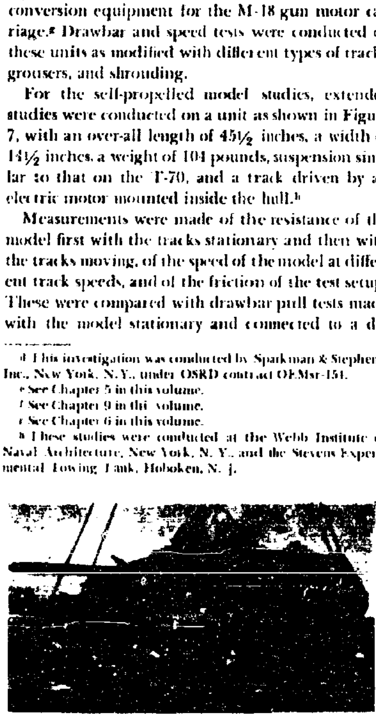


FIGURE 6. Experimental installation of simple track shrouding for submerged track propulsion study on T-70 gun motor carriage.

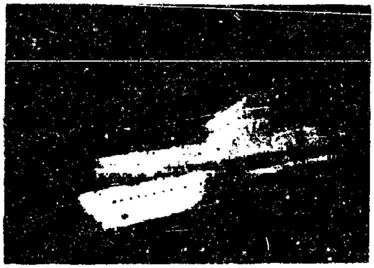


FIGURE 7. "Model 500," self-propelled model used in submerged track propulsion studies and shown equipped with bowblocks and medium skirt.

10.2.3 Results

From the detailed data,[1] it is possible to summarize the findings on both full-scale and small-scale models as follows:

Clearance

Proper clearance between the top of the track and the underside of the sponson can materially improve speed. With more efficient grouser-type tracks, minimum possible clearance may be most readily achieved. With less efficient tracks of the steel or rubber block type, increased clearance up to about 6 inches (the highest equivalent clearance tested) results in increased speed.

Bowblocks

The bowblock is the most important single item of shrouding, and should be provided in every case in as complete a form as possible. When possible, a bowblock design with full scoop should be used, and all efforts made to discharge the water from the return track tunnel through the largest angle down and back into the track. Discharge down and back is

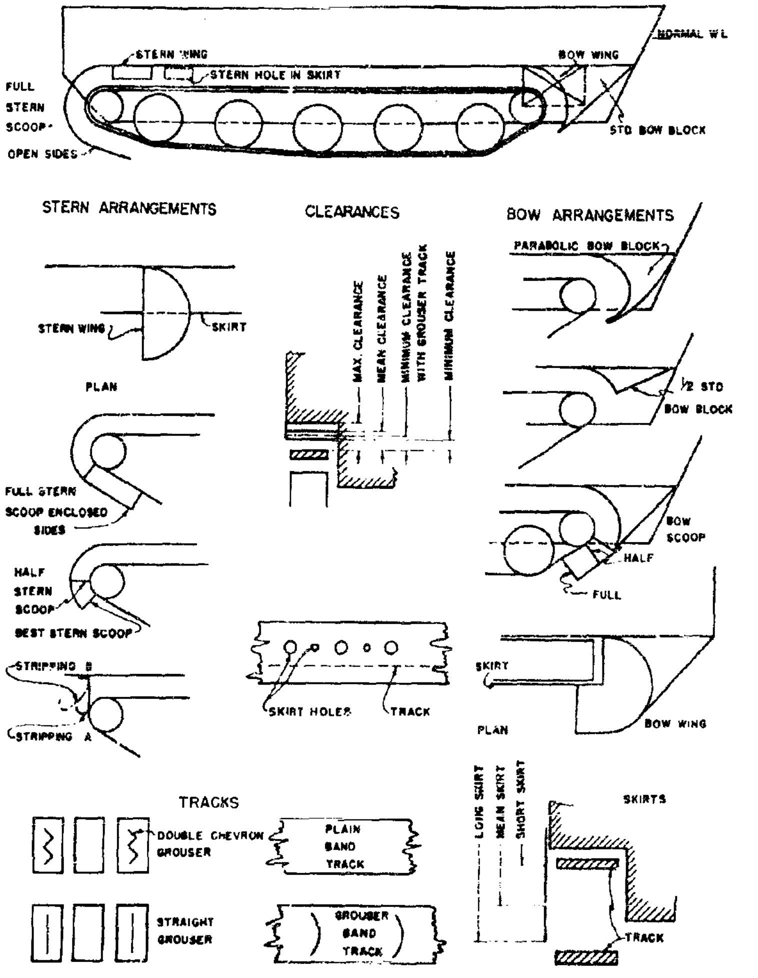


FIGURE 8. Details of track and shrouding components.

desirable even at the sacrifice of angle of turning, up to at least 60 degrees in some cases. In any given bow-block, the efficiency is increased by increasing the angle of turn from dead ahead to 180 degrees.

In all bowblock design, emphasis must be placed on providing free, unrestricted flow of water in and out at all times. Restrictions and conflicting flow patterns are definitely harmful.

Vulnerability and other considerations for land performance may occasionally limit the completeness of the bowblock to the extent that a removable or sliding block may be necessary for optimum amphibious operation. In cases where this is not practicable, the use of a stern wing as an alternate is suggested.

Track Skirts

From tests on both small- and full-scale models, it was found that track skirts extending to the hull bottom must be used to increase thrust and reduce resistance. To permit track servicing and track clearing in mud, they should be hinged at the sponson line. Since the skirts are exposed and subject to damage, special care should be given to support them at both top and bottom, and to permit quick removal.

Shaping the skirt to conform more closely to suspension outline is not expected to yield any marked improvement.

Track Skirt Holes

The tests show that these holes help slightly with block tracks and hinder with grouser-type tracks. Experimentation with track skirt holes may therefore prove fruitful where the track has relatively small grouser area and limited clearance. In this case, holes in the after end of the skirt and above the return track are those most likely to improve performance, but the anticipated improvement is slight.

Stern Arrangements

Careful design and application of the stern scoop should yield marked improvement in water speed. For highest speed, the scoop should extend down to at least the center line of the rear idler.

Stripping at any point in the track travel path is harmful.

The stern wing should be considered only when a substitute for a bow scoop is necessary. For both land and water operation, the wing has practical disadvantages which should be included in any considerations for application. Careful investigation of clearance over the track forward of the wing is recommended for improving track performance.

Tracks

In general, track design must be guided by relative importance of land performance and water performance and similar over-all considerations.

Where performance in water is paramount, the best track is the double chevron type, with the grousers about 3 inches high. Track efficiency increases with track and grouser width throughout the range tested, and accordingly the track should be as wide as possible.

Where performance on land and performance in water are about equally important, the standard rubber or steel block track with the steel or rubber chevron grouser and wing end connector extensions are recommended. These and all grouser tracks should be run with the open end leading.

Where land performance is the primary consideration, the track selected for optimum land operation will give reasonably satisfactory water performance if the recommended shrouding is used.

The primary consideration in designing a track for water propulsion is the direction of a high percentage of the total water moved by the track in the direction of track motion. Thus, grousers or webs which have a minimum of edge leakage have correspondingly high efficiency.

Lightening or mud clearing holes through the track block should be used where these will improve performance other than water propulsion.

Track Depth

Efficient design should guarantee complete submergence of the entire track under all conditions of water operation. The water line should be well above the sponson lines and far from the return track levels. This is significant not only for amphibians with all tracks submerged, but also for those with the return tracks emerged, and these should have the return track no less than 1 foot above the water line.

The submerged return track design is generally favored by considerations of land performance. It makes possible shorter tracks, better suspension systems, and greater stability on land and in water as a result of better weight distribution. Experience has shown that, in the case of combat amphibians, the submerged return track design minimizes chances

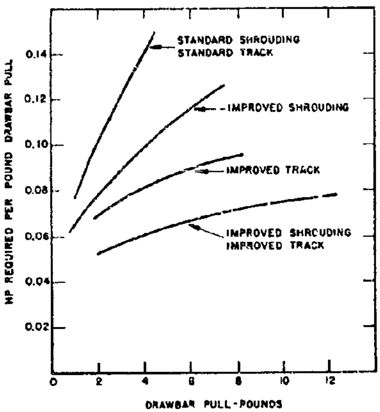


FIGURE 9. Effect of shrouding and track design on track propulsion. Standard is mean skirt, standard bow block, block track. Improved is mean skirt, full bow scoop, best stern scoop, ¼-inch double chevron grouser, 2 inch pitch on block track.

of enemy detection by means of phosphorescent track spray.

10.2.4 Conclusions

In general it was found that in no case does efficiency of track propulsion approach that which can be expected from screw propellers.

Drawbar pull is a good criterion of relative propulsive efficiency.

The extent of improved performance due to better shrouding is independent of that due to track design, and the two may be combined together for maximum improvement (Figure 9).

Recommended design features include a completely submerged track with a full bow scoop, a medium skirt, and a stern scoop, and a track with grousers formed for efficient motion of the water in the direction of track motion. Minimum practicable clearance should be provided between the upper tips of the return track and the underside of the sponson. The dimensions, suspension, track, power train, and all items except hull and weight distribution should follow requirements for land performance.

Regardless of whether the vehicle is designed with emerged or submerged return track in any condition of trim or loading, this track should never operate at less than 1 foot from the water surface.

All track-laying amphibians should be equipped with the best practicable shrouding, regardless of the means of propulsion used, to reduce resistance and provide normal or emergency water operation.

In analysing submerged track propulsion it should be noted that the action is not basically comparable to paddle wheel propulsion, and that more power is dissipated at turns in the track than in the straight portions.

10.3 ASSAULT ACROSS MUD

At the request of the Amphibious Section, COMINCH, means were studied for assaulting across mud. Rocket-propelled landing craft were proposed, and rough performance estimates made in conjunction with Divisions 6 and 8.[4]

The tactical assumption was made that a nonstop ship-to-shore passage across all types of mud provided the most powerful assault doctrine. To meet these requirements, it is essential to keep unit ground pressure low (for soft mud), and to provide high thrust (for dry and sandy mud).

It was found that although rocket propulsion offers distinct possibilities for an assault across mud, the range would be extremely limited by the basic inefficiency of rocket propulsion at the relatively low speeds involved. The problem of obtaining continuous propulsion by successive discharge of rockets was not studied in detail, but does not appear to offer a simple solution.

Figure 10 shows the relationship between time and distance, the latter expressed as the ratio between the distance travelled and the square root of the length of the vehicle. Each curve represents a different value of *I*, which equals the ratio of jet reaction to displacement. Figure 11 shows the relationship between time and speed, the latter expressed as the ratio between the velocity and the square root of the length of the vehicle.[5]

Designs were prepared to meet the requirements by mounting jet units on a V-bottom hull (Figure 12) and on an inverted V-bottom hull (Figure 13). The designs were not adopted, preference being shown for an air-propelled scow towing a Weasel across the soft mud, the troops to transfer to the Weasel if the mud becomes dry, sandy, or inclined.

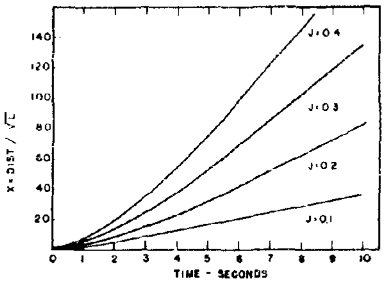


FIGURE 10. Relationship between time and distance traveled by rocket-propelled landing craft over mud.
J = ratio of jet reaction to displacement,
L = length of vehicle.

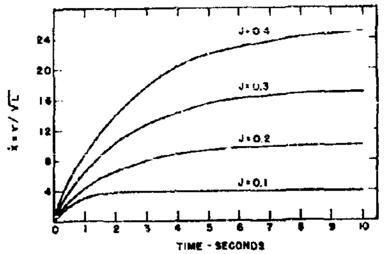


FIGURE 11. Relationship between time and speed of travel by rocket propelled landing craft over mud.
J = ratio of jet reaction to displacement,
L = length of vehicle.

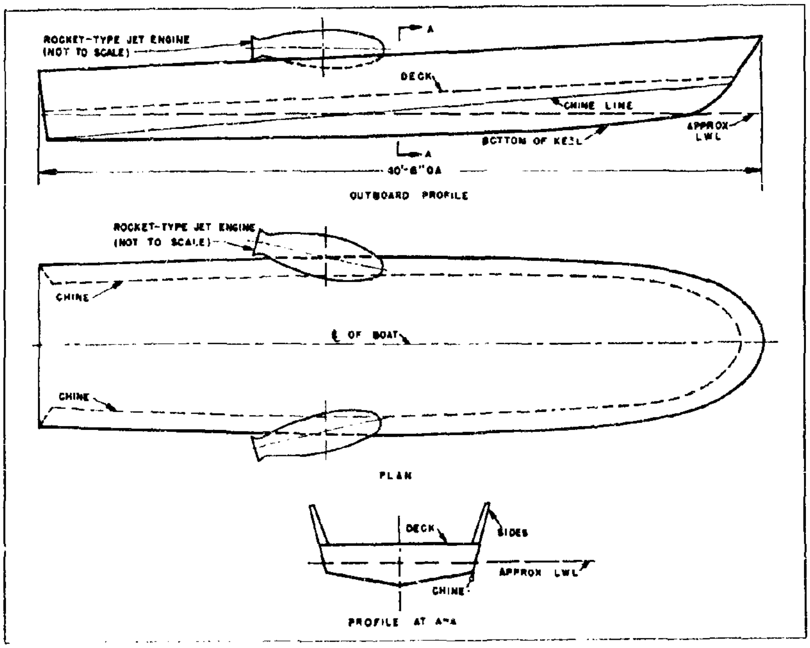


FIGURE 12. V bottom, jet propelled assault landing boat.

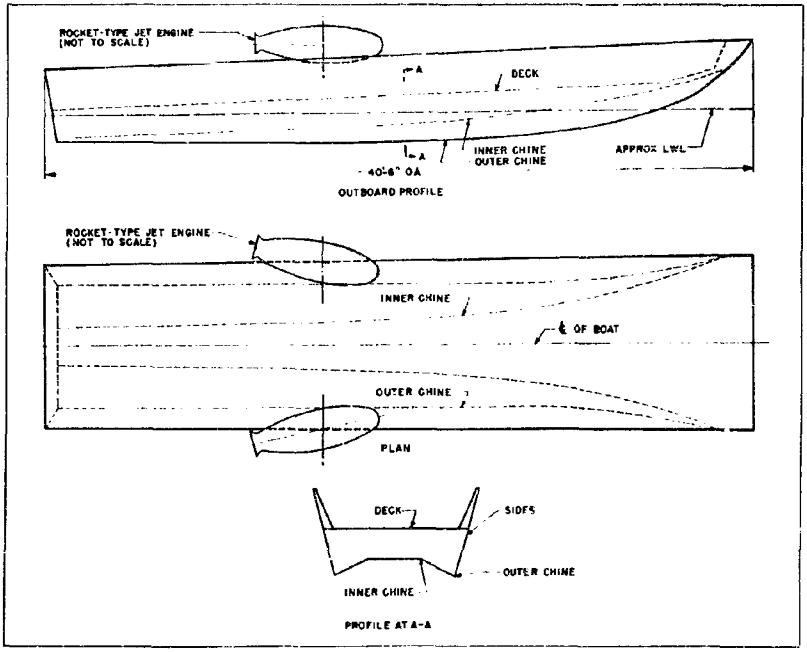


FIGURE 13. Inverted V bottom, jet propelled assault landing boat.

10.4 FUNDAMENTALS OF AMPHIBIOUS VEHICLE DESIGN

Summary

A survey of the development of amphibians makes possible an evaluation of the relative merits of ground-up designs and conversion designs, and a consideration of the fundamental principles involved.

10.4.1 Introduction

With the completion of amphibious design studies under the direction of Division 12 of NDRC, a survey[4] of the significant problems involved has indicated various principles and procedures which may be useful in future investigations.[1]

In this report, some of the conclusions are derived from experimental and field data. Others are opinions based on preliminary observations or considerations.[3]

10.4.2 Design Procedures

The development of all amphibious vehicles can be divided roughly into two broad categories—*ground up designs* and *conversion designs*.

GROUND-UP DESIGNS

Designing from the ground up, which yields a completely new vehicle, is the method followed almost

[1] For supporting data and other information, see the bibliographies for Chapters 2 to 9.

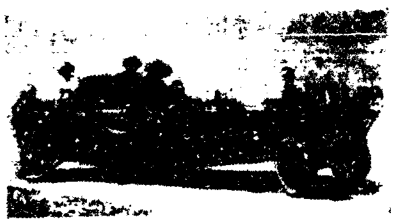


FIGURE 14. Jagger 1926 amphibian using Ford Model T components with chain drive to rear wheels and removable paddle wheels for water propulsion. Water speed about 4 mph.

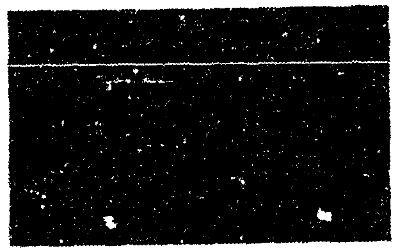


FIGURE 15. Jagger 1928 "Honukai" using Ford Model A components with twin propellers mounted above rear axle, one on each side of differential. Water speed about 5 mph. Springing of rear axle was eliminated after early trials.

exclusively before 1941 and used by some designers after that date. It offers complete freedom to the designer, permitting the use of new or standard components in any proportion or any arrangement.

Typical of the wheeled vehicles designed in this manner are the following:

1. The 1926 Jagger amphibian using Ford Model T components, with chain drive to the rear wheels and removable paddle wheels for water propulsion (Figure 14).

2. The 1928 Jagger Honukai using Ford Model A components, with twin propellers mounted above the rear axle, one on each side of the differential (Figure 15).

3. A German wheeled amphibious scout car demonstrated in 1937 (Figure 16).

4. A German scout car, captured in France in 1944, which has a mechanical power take-off from the vehicle engine and a retractable outboard drive with a single screw propeller off the stern (Figure 17).

5. The 4x4, ¼-ton Aquacheetah first demonstrated in May 1941 and improved in 1942 (Figure 18).

6. The British 8x8, 5-ton Terrapin Mark 1 and Mark 2 amphibious cargo carriers powered by two Ford V-8 engines and designed to be manufactured quickly even though certain disadvantages, including lack of maneuverability on land, were apparent.

Among the track-laying amphibians designed in this way are the Roebling Alligator, later modified and used by the U. S. Army (Figure 19), an experimental amphibious light tank equipped with a screw propeller and demonstrated by the Japanese in 1939 (Figure 20), and a Japanese twin screw-propelled

FIGURE 16. German amphibious wheeled scout car demonstrated in 1937.

FIGURE 17. German amphibious wheeled scout car, captured in France in 1944, propelled by retractable outboard drive. Marine power provided by mechanical power take-off from vehicle engine.

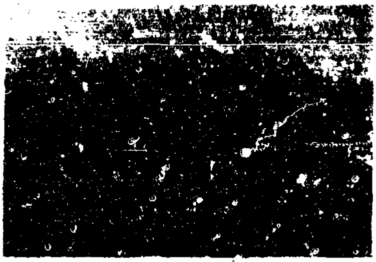


FIGURE 18. 1942 model of "Aquacheetah" representing "ground-up" design of ¼-ton 4x4 amphibian built by Amphibian Car Corp.

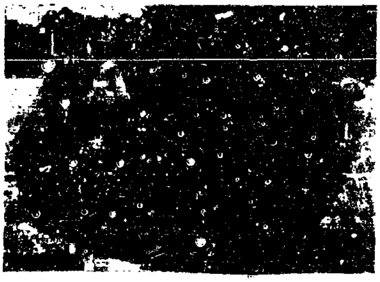


FIGURE 19. Early model of "Alligator" track propelled amphibian representing "ground up" design by John A Roebling.

light tank, captured in 1944, designed for intermittent amphibious operation with bow and stern pontons which are closely integrated with the main hull but which can be readily jettisoned for land operation (Figure 21). The outstanding development in this class is the LVT [Landing Vehicle, Tracked], which was extensively used in various forms by the Armed Forces of the United States and Great Britain (Figure 22).

Despite the usefulness of ground-up designing, experience has shown that this method has its inherent disadvantages, notably the serious mechanical and production problems which almost invariably arise during the development of any completely new chassis. The development of satisfactory land performance becomes an unavoidably long program. Basic design changes often are found to be necessary only after extended field trials and actual combat operation.

The ground-up method is recommended if funds, development facilities, and especially time are all abundantly available. If any of these factors is limited, as in time of war, careful evaluation of the overall program is essential.

CONVERSION DESIGNS

In contrast to the ground up method is the conversion design, which converts a standard land vehicle or its chassis into an amphibious vehicle—a procedure which, to a very large extent, was originated by Division 12 of NDRC and its contractors. Here the designer has the advantages—as well as the limitations—of starting with a basic structure selected for its land performance, its known reliability, and its availability for production.

In a few instances, the conversion may be for only

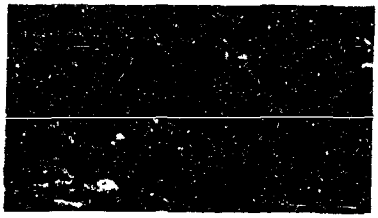


FIGURE 20. Experimental screw propelled amphibious light tank demonstrated by Japanese about 1939.

FIGURE 21. Japanese "ground up" light tank design for intermittent amphibious operation. Bow and stern pontons are closely integrated with main hull but are readily jettisoned for land operation. Twin screw propelled. Model shown captured summer 1944.

FIGURE 22. Unarmored LVT(2) track-propelled cargo amphibian.

temporary amphibious operation, and the land vehicle is equipped with detachable floats or pontons which provide the necessary added buoyancy, reduce water resistance, and sometimes act as shrouding to improve propulsion by tracks. This method is illustrated by an early use of side pontons on the 4x4, ¼-ton truck (Figure 23), and by the Ritchie T-6 device, which consists of metal pontons attached to the M-4 medium tank to give satisfactory speed and general performance in water (Figure 24). The pontons may be readily jettisoned for land operation of the tank.

For permanent amphibious operation, a watertight hull is fitted around a standard land vehicle chassis so that it will perform satisfactorily both on land and in water.

Permanent amphibious wheeled vehicles include the DUKW 6x6, 2½-ton cargo carrier (Figure 25) and the GPA 4x4, ¼-ton cargo carrier (Figure 26). Here the land body is replaced with a new amphibious hull. The wheels, suspension, drive shafts, differential and pertinent supports, all taken from the standard chassis, become wet appendages housed to

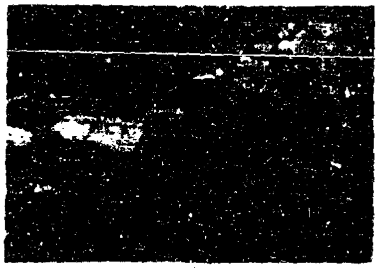


FIGURE 23. Early "temporary conversion" of ¼-ton, 4x4 truck demonstrated in 1941.

varying degrees in tunnels (Figure 27), while the frame, engine, power train controls, and auxiliary equipment are housed within the watertight hull. Provisions are also made for sealing against water entrance, providing engine-cooling air through protected inlets and outlets, screw propeller drive for water operation, rudder steering, and numerous accessories and refinements for both land and water operation. Safety devices, including folding surf plates, power-driven bilge pumps, and coamings must likewise be included.

One type of permanent conversion for track-laying vehicles is shown by the conversion of the M-29 Weasel light cargo carrier to the M-29C Weasel amphibious light cargo carrier (Figure 28). This was accomplished by the addition of watertight bow and stern cells, track shrouding, rudder steering equipment, and such auxiliaries as a surf plate and a power-driven capstan. Water propulsion is obtained from the standard M-29 land track with shrouding

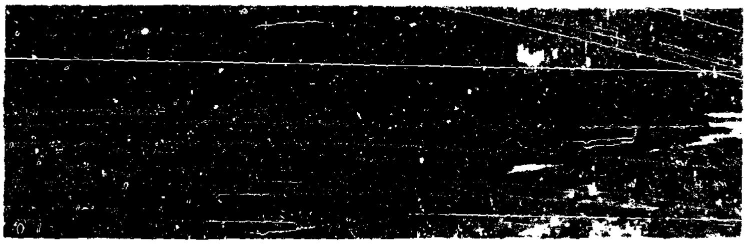


FIGURE 24. M-4A1 medium tank equipped with Ritchie T-6 flotation device.

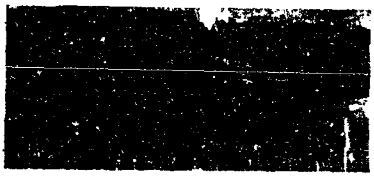


FIGURE 25. Late 1944 production model of 2½ ton, 6x6 DUKW.

developed to increase the effective thrust of the moving track.

Another type is illustrated by the conversion of the M-18 76-mm gun motor carriage to the T-86 amphibious gun motor carriage (Figure 29). In this case the standard hull from the sponson up was removed and replaced with a new, larger, watertight hull with a raised turret and ends designed for increased buoyancy and decreased resistance.

In general, this method of design was adopted in 1941 in order to expedite the development and production of urgently needed vehicles. It provided the designers with engineering and field experience based on standard, proved chassis, enabling them to devote most of their efforts to marine performance and requiring only refinements of land performance. Existing production equipment and assembly methods could be adopted, often without change, and maintenance in war theaters could be based on available methods and spare part supplies set up for the parent vehicles.

Inevitable disadvantages were inherent in this method, since the parent vehicles had been designed with little or no thought given to operation in water. Only rarely did the original weight, arrangement, and materials meet amphibious requirements. On the other hand, these disadvantages were offset to some degree by the large number and variety of land vehicles available for selection as the parent vehicle, the contemporary development of improved components, and the ability to incorporate into production models certain modifications found desirable or necessary for amphibious operation.

Because time was so important, it is believed that the conversion design method has amply justified its use. Its introduction and adoption in 1941 as a major design procedure resulted in developing and *delivering* useful vehicles to the Armed Forces more

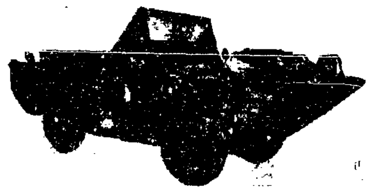


FIGURE 26. Production model of amphibious jeep.

quickly than would have been possible by any other means.

10.4.3 Basic Specifications

In outlining principles and correlating information, the bulk of the material presented here represents data obtained from amphibians which are permanent conversions of standard land vehicles or their chassis. While this applies in particular to conversion designs, the principles apply generally to all amphibians, with only slight reservations in some cases. Vehicles for only military use are considered here.

In the design of a new amphibious vehicle, certain basic limitations are involved. Some of these are defi

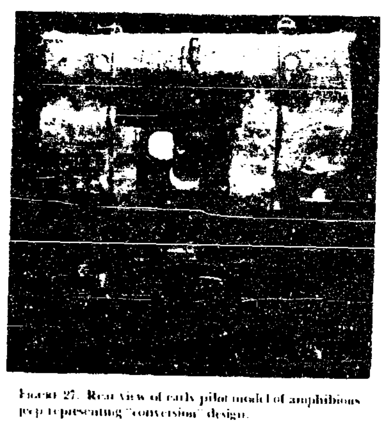


FIGURE 27. Rear view of early pilot model of amphibious jeep representing "conversion" design.

nite, while others require a compromise based on the judgment of the designer. Over-all width and weight, for example, are definite specifications, with width usually limited by considerations of rail transport or the width of military roads and bridges; gross and light weight may be rigidly determined by the proposed use of the vehicle and by the size of the available engine in combination with the size of the hull.

Less definite but nonetheless limiting specifications include over-all height, which must be a minimum for land operation to reduce exposure to enemy fire and a maximum to provide adequate freeboard in water and adequate driver vision on land. Over-all length must be determined by such factors as maneuverability on land, suitable angles of approach and departure, driver vision, and adequate protection of cab and openings from surf and rough water.

Because in many cases the final design details represent a compromise between the conflicting requirements for land operation and water operation, in most respects the amphibian becomes inferior in water performance to a comparable boat and inferior in land performance to a vehicle designed solely for land transport. It is inferior to a boat in having high resistance, due largely to numerous appendages and to greater weight for the same job. It is inferior to a land vehicle in having greater bulk, because of the necessity for providing buoyancy, and an excess of mechanical parts, essential for propulsion in the water.

On the other hand, the amphibian possesses certain marine advantages over its boat counterpart, as well as land performance advantages over its parent land vehicle.

FIGURE 28. Side view of early model of M-29C amphibious Weasel representing "conversion" design. This represents conversion of nonamphibious M-29 Weasel by addition of bow and stern cells, track shrouding, and rudder steering.

Figure 30 and Table 1 together serve to compare a typical amphibian, the DUKW, with its parent truck and with two corresponding boats. The characteristics they evaluate are true to different extents for all amphibians. Future development should aim at reducing these differences.

HULL TYPE

It will be shown later that the length, width, height, angles of approach and departure, and ground clearance define the block or envelope within which the amphibious hull must fall. The designer may exceed these limitations only when this is warranted by an inescapable compromise; otherwise, the limiting dimensions can be outlined immediately for the

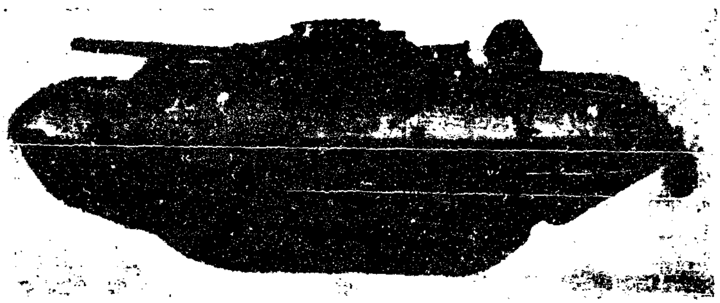


FIGURE 29. Side view of pilot model T-86 amphibious gun motor carriage.

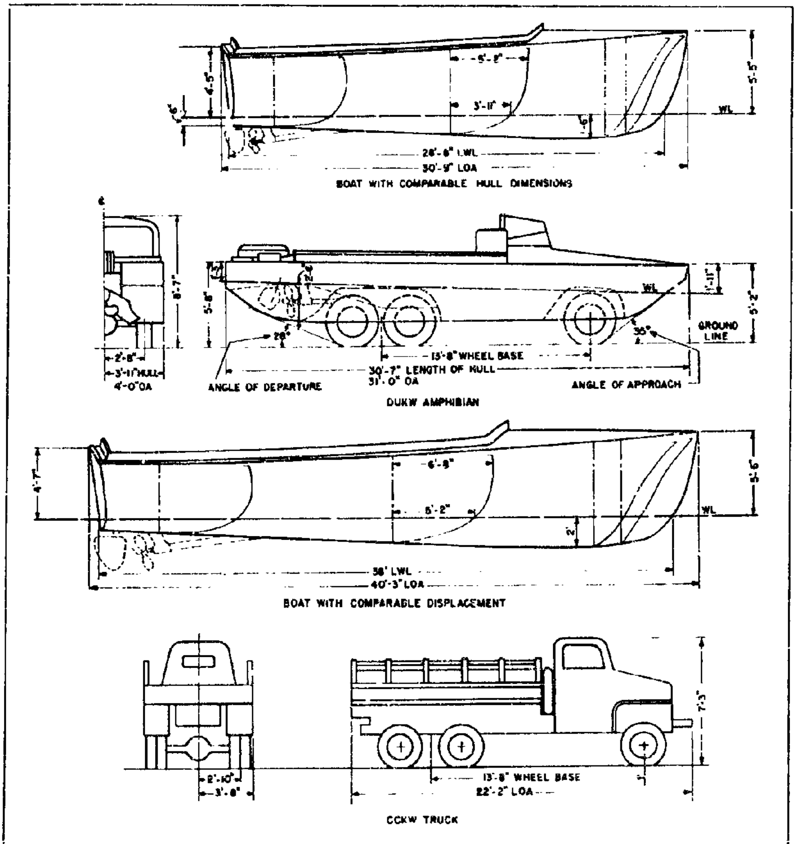


FIGURE 30. Comparison of DUKW amphibian and parent CCKW truck with Boat A (comparable hull dimensions) and Boat B (comparable boat displacement).

wheeled, track-laying, half-track, or tractor-trailer amphibian.

The best of all hull types tested for the DUKW is a scow type with full ends and with wet appendages housed in tunnels (Figure 31). This design provides for maximum buoyancy with limited over-all dimensions. Full ends are useful in entering or leaving the water over a steep bank, and their buoyancy helps to prevent swamping. Tests proved conclusively that, for appendages such as wheel and differential casings, the greater the housing in a tunnel, the less the resistance in the water. Tunnels, moreover, protect ap-

TABLE 1. Comparison of a Successful Amphibian (DUKW) with Two Corresponding Boats and Its Parent Land Truck.

Items	Amphibian	Truck	Boat A	Boat B
General description	DUKW—2½ t.—6x6 wheeled amphibious cargo carrier with winch	CCKW—2½ t.—6x6 cargo long wheelbase—with winch	General purpose boat with same WL length and beam as DUKW	General purpose boat with same displacement as DUKW
Hull type	Scow type—wheels, housed wheels, axles, drive shafts, differentials, brakes—wet—in tunnels	....	Round bottom non-planing	Round bottom non-planing
Length over-all (inches)	372	267	369	485
Breadth over-all (inches)	96	88	324	160
Height over-all in water (from WL) (inches)	59	....	72	74
on land (over cab) (inches)	103	87	....	....
Length load water line (LWL) (inches)	314	....	314	456
Maximum beam at water line (inches)	94	....	94	124
Maximum hull draft—loaded in sea water (inches)	30	....	18	24
Loaded freeboard to deck in sea water (64 lb/cu ft) over bow (inches)	25	....	65	66
amidships (inches)	19	....	52	54
over stern (inches)	15	....	53	55
Displacement or weight—loaded (pounds)	20,000	15,900	8,100	20,000
light (pounds)	15,000	10,900	5,400	9,500
Normal payload (pounds)	5,000	5,000	2,700	10,500
Pounds payload per pound of weight light	0.33	0.46	0.50	1.10
Cargo floor area (square feet)	85	80	120	210
Cargo volume—top of coaming (cubic feet)	198	280	510	1,050
Ground clearance (min. at front axle) (inches)	11¼	10	....	...
Ground clearance btwn front and rear wheels (inches)	18½	17	....	...
Angle of approach (degrees)	38	5[illegible]	....	....
Angle of departure (degrees)	23	36	....	....
Beam-draft ratio (fully loaded)	3.11	..	5.21	5.16

Items	Amphibian: Based on actual displacement to load water line	Amphibian: Based on hull with no cutouts or appendages to same WL	Truck	Boat A	Boat B
Displacement length ratio $\frac{\text{displacement}}{(\text{LWL}/100)^3}$ $\frac{\text{long. tons}}{\text{ft}^3}$	378	369	...	153	163
Block coefficient $\frac{\text{volume displacement}}{\text{LWL} \times \text{Max. beam} \times \text{draft}}$	0.557	0.823	...	0.371	0.398
Longitudinal prismatic coef. $\frac{\text{volume displacement}}{\text{max. section area} \times \text{LWL}}$	0.671	0.853	....	0.566	0.566

TABLE 1. (*Continued*)

Items	Amphibian	Truck	Boat A	Boat B
Range of operating speed-length ratio $V/\sqrt{L}$ $\frac{\text{speed}}{\sqrt{\text{LWL}}}$ $\frac{\text{knots}}{\sqrt{\text{ft}}}$	0.7–1.0	...	0.9–1.5	0.9–1.5
Speed at $V/\sqrt{L} = 1.0$ mph	6.16	....	6.16	7.09
Total resistance in pounds per long. ton displacement at $V/\sqrt{L} = 1.0$	124	....	21	24
Total resistance (fully loaded) at $V/\sqrt{L} = 1.0$ lb	1,100	....	76	215
Wetted surface (square feet)	740	....	210	370
% residual resistance of total resistance	85	....	32	28
Transverse metacentric height (GM_T) (inches)	25	....	47	82
Longitudinal metacentric height (GM_L) (feet)	48	....	58	75
Moment to trim 1" on load WL (foot-pounds)	2,790	....	1,370	3,290
Pounds per inch immersion load WL	1,190	....	870	1,532
Typical propellers	1–3 blade –25" diam. x 11" pitch at 1,100 rpm	....	1–3 blade – 18" diam. x 16" pitch at 500 rpm	1–3 blade – 20" diam. x 16" pitch at 625 rpm
Wake fraction	[illegible]	....	[illegible]	[illegible]
Thrust deduction	0.30	....	0.10	0.10
Propulsive coef. = $\frac{\text{tow rope hp (per cent)}}{\text{engine brake hp}}$	20	....	55	55
Apparent propeller slip (per cent)	58	...	15	22
Miles per gallon gasoline over operating speed range in water	0.8 @ 6 mph–2.3 @ 4.2 mph	....	13.0 @ 6.4 mph	7.4 @ 7.4 mph

pendages from damage in shallow water and on land. Impact and concentrated loads resulting from cross-country operation require that the hull be strengthened well beyond marine requirements and demand that metal be used for the hull shell.

In comparison, for Boats A and B (Figure 30 and Table 1), greater latitude of hull form is permissible because no land performance is involved, and the hulls can be designed simply for space, speed, or considerations of cost. A round bottom is selected as being typical for comparable speed ranges. The material used in construction need not be metal, and protection from local impact is not as vital as in the case of the amphibian.

Similarly, greater leeway is permissible in the design of the land truck body, and the construction may vary according to the purpose of the vehicle, the general type of its cargo, and the methods to be employed in loading and unloading it.

LENGTH

The DUKW is substantially shorter than a comparable boat with the same displacement. This is necessary to maintain satisfactory maneuverability on land, but unfortunately it increases resistance in the water and adds to the draft or the beam (up to the over-all width limitation) or both.

In the same way, the length of a full track-laying amphibian is still further limited for satisfactory land maneuverability, particularly for adequate angles of approach and departure. For an allowable center-of-track to center-of-track dimension, the length of track on the ground is clearly limited by the degree of maneuverability desired.

A half-track or ¾-track vehicle such as the proposed model shown in Figure 32 offers the most satisfactory method of increasing the over-all length, while a tractor-trailer such as the proposed unit shown in Figure 33 offers potentially greater length

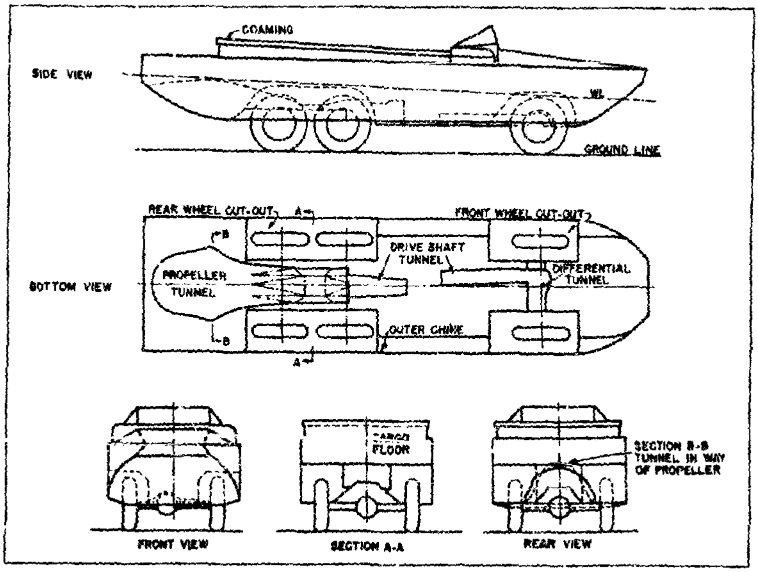


Figure 51. Hull of 2½ ton, 6x6 DUKW amphibian showing tunnels and cutouts.

with satisfactory maneuverability on land. For amphibians of high gross weight—35,000 pounds or more—either of these types is recommended in place of the full-track or wheeled amphibian, and would offer better arrangement, greater cargo space, and better water performance.

Length, therefore, is determined essentially by land requirements. The length of an amphibian can be that of a comparable land vehicle plus end extensions, with consideration for satisfactory angles of approach and departure.

Width

The width of the DUKW is also limited by land specifications. Rail transport limits such a vehicle to 121 inches, while military bridges and roads may reduce the maximum width to 96 inches. In contrast, a similar boat may have a beam far surpassing such limits.

Height

The over-all height of an amphibian must be determined by an arbitrary decision based on judgment and experience, and on such factors as maintaining a low profile to reduce exposure to enemy artillery fire, keeping the deck height down in order to facilitate loading and unloading, maintaining sufficient freeboard and reserve buoyancy for rough water operation, and providing a satisfactory vantage point for driver vision in land operation.

These limitations do not affect such water craft as Boats A and B, or are not critical.

Loaded Freeboard

The DUKW freeboard of 23 inches to the deck at the bow and 15 inches at the stern is apparently just enough for all-around seaway and surf operation, provided that all cooling-air inlets and outlets, cargo spaces, and other large openings are protected or

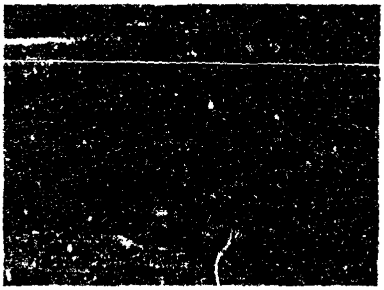


FIGURE 34. Climbing steep river bank, rear deck of amphibious jeep is partly submerged. Most entries down such banks similarly immerse foredeck.

parable boats, and consequently gives lower transverse form stability. Compensation is provided in part by increased displacement of the amphibians a lower center of gravity, and an appendage effect.

Displacement-Length Ratio

This ratio is inevitably high on amphibious vehicles because of unavoidably high weight and limited over-all length, and indicates a relatively high hull-form wave-making resistance. This ratio is about 1,300 in the LVT(4), and about 569 in the DUKW. The possibility of substantially reducing this ratio is provided by the larger ¾-track or tractor-trailer unit amphibians.

Block and Longitudinal Prismatic Coefficients

These values, criteria of residual hull-form resistance, are high in amphibians because of the dimensional limitations involved.

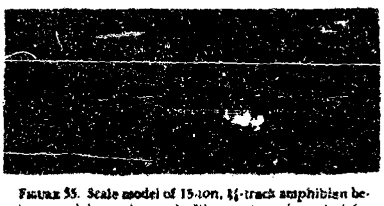


FIGURE 35. Scale model of 15-ton, ¾-track amphibian being tested in towing tank. Wave pattern is typical for amphibians operating at a speed equivalent to a speed-length ratio of 1.0.

Speed-Length Ratio

In military operations, the use of low-displacement boats may be predetermined by their practical operating speeds. Since less additional power is needed, they can be more easily designed for higher speeds than can comparable amphibians.

In the case of the DUKW, the operating speed-length ratio is relatively low, but at the sacrifice of

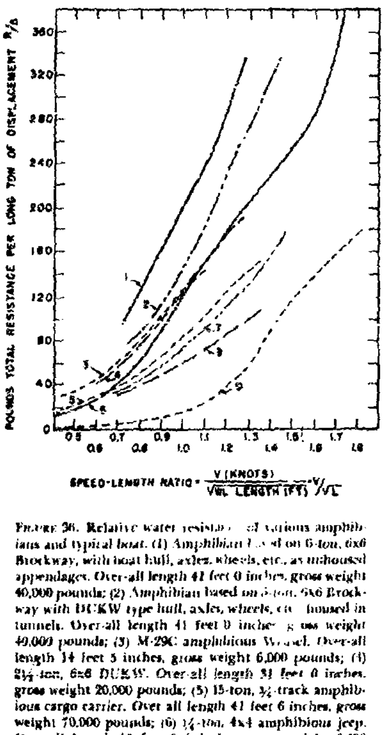


FIGURE 36. Relative water resistance of various amphibians and typical boat. (1) Amphibian based on 6-ton, 6x6 Brockway, with boat hull, axles, wheels, etc., as unhoused appendages. Over-all length 41 feet 0 inches, gross weight 40,000 pounds; (2) Amphibian based on 6-ton, 6x6 Brockway with DUKW type hull, axles, wheels, etc. housed in tunnels. Over-all length 41 feet 0 inches, gross weight 40,000 pounds; (3) M-29C amphibious Weasel. Over-all length 14 feet 5 inches, gross weight 6,000 pounds; (4) 2½-ton, 6x6 DUKW. Over-all length 31 feet 0 inches, gross weight 20,000 pounds; (5) 15-ton, ¾-track amphibious cargo carrier. Over all length 41 feet 6 inches, gross weight 70,000 pounds; (6) ¼-ton, 4x4 amphibious jeep. Over-all length 15 feet 8½ inches, gross weight 5,400 pounds; (7) LVT(2). Over-all length 24 feet 3 inches, gross weight 34,900 pounds; (8) T-86 amphibious gun motor carriage. Over-all length 29 feet 5 inches, gross weight 44,000 pounds; (9) Round-bottom pleasure cruiser (not an amphibian). Over all length 32 feet 7 inches, gross weight 13,200 pounds. All track-laying amphibians tested with tracks stationary.

FIGURE 57. Scale model of amphibian based on Brockway 6-ton, 6x6 chassis. This design emphasizes hull form, eliminates appendage tunnels. Resistance is higher than all other types of hulls tested.

fuel consumption and cruising range this vehicle can give higher speeds adequate to fulfill its missions.

RESISTANCE

Since it is determined largely by land requirements, the hull form of an amphibian generally has higher form resistance than does a comparable boat. Figure 55 shows the wave pattern typical for amphibians operating at a speed equivalent to a speed-length ratio of 1.0. Appendage resistance more than doubles hull resistance.

The relative resistance of a number of wheeled, full-track, and ¾-track amphibians and a round-bottom, nonamphibious pleasure cruiser is indicated by the curves in Figure 56. These show that while the resistance per ton varies over a wide range, the lower limits for amphibians are well above the upper limits for comparable boats, due to high basic hull-form resistance and to extremely high residual resistance caused by numerous appendages.

The curves likewise show that the total resistance of a given amphibian does not vary with displacement in any approximate ratio. This is true since practically all the amphibian's appendages are immersed even when the vehicle is unloaded, and their resistance does not increase in proportion to an increase in vehicle draft. Thus, the low values of resistance per ton of displacement for the LVT, the ¾-track, and the T-86 are due in large measure to the higher displacement and lower appendage resistance of these vehicles.

The amphibian model based on the Brockway is pictured in Figure 57. With a design emphasizing hull form and eliminating tunnels for appendages, its resistance was found to be higher than that for any other vehicle model tested. It represents the extreme in high resistance for a vehicle designed to fit inside the dimensional limits set for optimum land performance. It may be compared with the DUKW which,

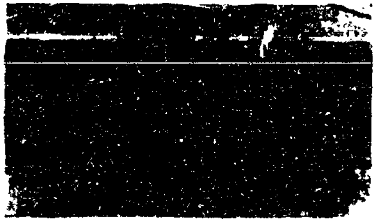


FIGURE 58. Stern view of T-86E1 gun motor carriage showing how housing propeller in tunnel limits diameter and produces high wake fraction and thrust deduction.

while also remaining within the prescribed limits, has a vastly lower resistance because of tunnels and shrouding.

The gap remaining between the DUKW and the boat, however, indicates that considerable improvement is still needed in amphibious design.

As a consequence of their high resistance, amphibians have low maximum speeds and extremely high fuel consumption, and need relatively large engines. Although an engine which will operate satisfactorily in a military land vehicle can develop sufficient power for marine operation, in the latter it is often required to perform over long periods at full power. This increases wear, makes cooling more critical, and requires more servicing.

PROPULSIVE COEFFICIENT

Although the higher total resistance of an amphibian calls for greater propeller power, the diameter of the propeller is usually limited by the necessity for protecting it in both shallow water and land operation, and the propulsive coefficient of amphibians is consequently low.

Since the hull form as determined by factors described above has an inherently high wake fraction and a high thrust deduction (Figure 58), a propeller in a practicable tunnel cannot fully attain the advantage of wake, and reduced pressures on the tunnel surfaces forward of the propeller cannot be completely avoided. This, too, contributes to a low propulsive coefficient.

It would be possible to increase this coefficient by using retractable propellers or by developing a mechanical arrangement which would provide for a better propeller tunnel design. The retractable pro-

FIGURE 39. First pilot model 2½-ton, 6x6 DUKW in moderate surf.

FIGURE 40. M-29C amphibious Weasel negotiating storm on Lake Michigan.

peller, however, was excluded because of the added exposure to damage, and the use of a standard chassis inhibited any significant improvement in tunnel design.

STABILITY

Because of increased weight for the same water plane area, the DUKW has lesser transverse and longitudinal metacentric heights. Since righting moment is a function of both displacement and metacentric height, this increased weight counterbalances the reduced metacentric height, giving approximately the same *static* stability.

The hull form used in the amphibian has improved *dynamic* stability because of its numerous tunnels and appendages. These affect the action of the vehicle in rolling, pitching, and heaving in two different ways. First, by increasing the effective mass of the vehicle in motion (due to entrained water), rolling, pitching, and heaving are made more "easy" and motion due to impact is reduced in amplitude. Second, due to the high resistance of tunnel sides and edges and of the numerous appendages, especially the wheels, velocity of roll and acceleration due to impact are both decreased, and the "decrement of oscillation" or damping is increased.

The combination of these factors with the higher initial mass and the lesser metacentric height increases the period of roll and decreases its amplitude, resulting in a substantial improvement in seaworthi-

FIGURE 41. DUKWs approaching Normandy beachhead on D Day, June 6, 1944.

FIGURE 42. Pilot model 1/4-ton, 4x4 amphibious jeep entering moderate surf.

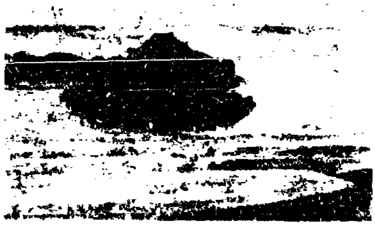


FIGURE 43. DUKWs operating off Fort Ord, California, in surf about 8 feet high.

ness, crew comfort, and cargo safety (see Figures 39, 40, and 41).

SURF ABILITY

The performance of the amphibians in surf has proved satisfactory and consistently superior to comparable boats (Figures 42, 43, and 44), and the difficulties have been almost entirely limited to those involved with sealing or protection from surf impact.

Ability to operate in surf is improved by a number of factors which thus far cannot be objectively assayed. The reduced freeboard at the ends reduces the area of possible surf impact, and as a result the oncoming or trailing surf frequently breaks on the end decks, dissipating its energy without causing excessive pitching. The reduced reserve buoyancy at bow and stern also serves to limit the trimming moment of large waves and therefore the magnitude of pitching. The wheels or tracks on an amphibian assist in steering and controlling the vehicle when in contact with bottom, particularly during landing, and under certain conditions make it possible to build up ample momentum while landborne to carry the vehicle through the surf. The resistance of appendages to lateral movement assists in keeping the vehicle in proper position to the surf. The amphibian has the inherent ability to depart from the surf quickly, reducing the possibility of foundering or damage.

PROTECTIVE SEALING

The low freeboard on all amphibious vehicles requires special attention to the protection of necessary openings. At the same time, low reserve buoyancy demands satisfactory sealing of the immersed hull and a reliable bilge pumping system with adequate capacity.

In spite of temporary expedients adopted, experience has proved the necessity of waterproofing the engine, control, and electrical components. Field kits for waterproofing, including sealing compounds, waterproofing sprays, tape, and special greases, have been effective only for temporary use and only if they are properly used. Permanent amphibians require factory-waterproofed components, including the instrument panel, junction boxes, wiring, and engine ignition.

Since exposure to spray and water is inescapable with present designs, corrosion-resistant materials must be specified wherever they are needed. Difficulties experienced with exposed brakes indicate the desirability of housing brake drums and bands inside the hull wherever possible.

ARMOR PROTECTION

No adequate means have thus far been found for providing combat amphibians with satisfactory armor plate protection. The added weight which would detract from payload or add to gross weight has materially restricted its use.

FIGURE 44. [illegible] amphibious gun motor carriage (left) and [illegible] surf during tests at Fort Ord, California.

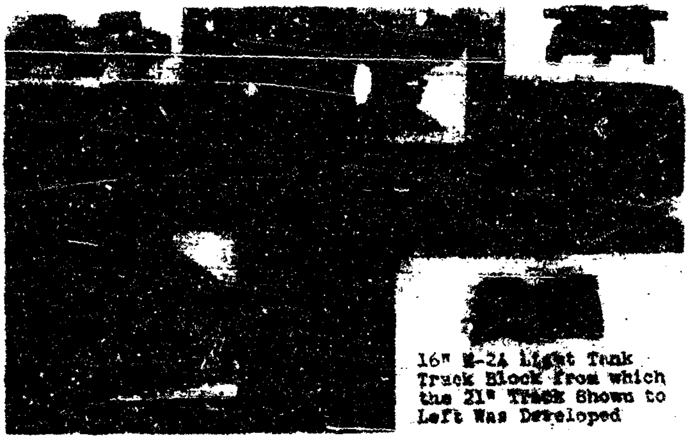


FIGURE 15. 21-inch wide track, with parent 16-inch wide track and replaced 12-inch wide track. Weights per linear foot of all three are approximately the same.

Some consideration has been given to providing local detachable armor protection to personnel and vital parts of the vehicle. A possible solution may lie in the use of detachable pontons which give added buoyancy and which can be jettisoned when the vehicle is landborne (Figures 21 and 24), but this still would have all the disadvantages of a nonpermanent conversion and of excess bulk.

The eventual solution seems to lie in the use of improved materials which would permit lower basic weights in the mechanical portion of the vehicle and provide greater ballistic protection for the same weight in armor plate.

Driver Vision

Satisfactory vision for water control usually presents no serious problems in amphibian design. The driver's steering station must be far enough aft and high enough above the water line to provide protection from spray, sufficient distance to the bow to facilitate steering, and a vantage point to give a range of vision which will be unaffected by small seas.

In contrast, numerous difficulties are involved in providing vision satisfactory for land operation. Driver vision on amphibians is thus far materially inferior to that on similar land vehicles, largely as a result of the necessary hull end design and the requisite low profile. In some cases, "vision blocks" and vision cupolas as used in the T-86 amphibious gun motor carriage (see Chapter 6) have proved useful on combat vehicles.

Marine Steering

Maneuverability is particularly important in amphibious operations, and a high degree of control is essential in entries and exits from the water. Such operations, and also operations across country, require that rudders used for steering must be protected by tunnels or so designed that they will swing clear if they strike an obstacle.

Marine steering equipment, including control from the land steering wheel, quick-acting mechanisms, an inclined rudder post, and an appropriate tunnel design, was developed satisfactorily in the DUKW amphibious program.

Loading and Unloading

The hull depth required for amphibians and the difficulty in sealing submerged hatch covers have together interfered with quick loading and unload-

FIGURE 46. Artist's conception of some proposed uses of DUKW: (1) ponton bridge, (2) vehicle ferry, (3) tank wet ferry, (3A) tank dry ferry, (4) light freight carrier, (5) heavy freight carrier, and (6) troop carrier.

ing, particularly on land. An additional restriction has resulted from the need for coamings and decking at the ends. The stern ramp used on some LVT cargo carriers has given some improvement, but new problems have been introduced by the power-driven ramp hoist, swamping over the stern, and the maintenance of the ramp seal.

MUD AND SAND OPERATION

The use of amphibians both on land and in water makes it essential that these vehicles also operate well on mud and sand. In general, this requires increased tire or track flotation. The M-29C Weasel amphibious light cargo carrier, with an average unit ground pressure of 2 psi, indicates the advantages of increased flotation, and at the same time has provided the Armed Forces with a vehicle which can successfully negotiate soft mud, marsh, swamp, volcanic ash, and soft sand.

The development of a 21-inch wide track for the T-86 amphibious gun motor carriage to replace the standard 16-inch track represents another approach to this problem. The new track, which gives improved operation in mud, uses the pitch and single pins of the old design but provides wing extensions, holes through the track block base, and a new web design. These modifications decrease the weight, assist in clearing mud from the tracks, and reduce the unit ground pressure (Figure 45).

In research on the DUKW, investigations on the type of tire and on the effect of tire pressure revealed methods for improving the performance of wheeled vehicles on mud and soft sand. Large single tires (as contrasted with dual tires) with low sidewall stiffness together with a central control system enabling the pressure in each tire to be controlled from the driver's station, were incorporated, giving the advantages of using low pressures for increased flotation on mud or sand and high pressures for longer life and lower rolling resistance on hard surfaces.

TRIM OF TRACK-LAYING AMPHIBIANS

In order to improve driver vision on land and to increase the dynamic freeboard forward, it is desirable to provide trim by the stern. With the limitations on hull form as outlined above and the necessity for keeping the center of gravity forward of the center of the ground contact length for efficient land operation, this trim is difficult to obtain.

USE OF AMPHIBIANS

It has already been emphasized that the best amphibians designed to date are inferior to comparable land vehicles for land operation and to comparable

boats for water operation. Obviously, use of the amphibian can be recommended only where one unit must operate in both environments. Tactical experience has shown that an amphibian should actually be employed when, in the judgment of the commanding officer, boats or trucks cannot do the work as well, as quickly, or with as few personnel. Among these applications are the following:

1. Landing of shore-based artillery early in the assault on a beach.

2. Landing operations where landing craft cannot operate because of heavy surf or offshore sand bars, reefs, or shoals.

3. Ship unloading over undeveloped beaches or in damaged ports.

4. Reconnaissance which may require deep water crossings.

5. Rescue work over courses where boats and land vehicles cannot operate.

6. Combat river crossings to establish beachheads.

7. Raiding operations or surprise attack missions.

8. Supply of otherwise isolated units in combat.

9. Ferrying of other vehicles or troops for dispersal, or where suitable facilities for boat disembarking are unavailable.

One concept of the various uses which were proposed for the DUKW is illustrated in Figure 46, which shows the vehicles operating as pontons for a bridge, and as ferries for troops, freight, tanks, and other vehicles.

The General Problem of Soft Terrain

No matter whether this country enters an atomic arms race or succeeds in suppressing atomic fission as a weapon, it will probably remain true that the Armed Services should possess large numbers of a great variety of amphibious vehicles able to perform many different types of missions over mud, snow, and quicksand. A good deal of thought has been given by the division and its contractors to this general problem of traversing soft terrain, and at one time or another during the past few years, designs were prepared for vehicles covering a wide range of unit ground pressures. The extreme case in this series is represented by a jet-propelled plywood vehicle designed for assault at high speed across short stretches of extremely soft mud.[j] Next in unit ground pressure is the Weasel,[k] next the paddy vehicle,[l] next the DUKW with its tires deflated,[m] and finally the tank destroyer or high-speed combat vehicle included in the Turtle series.[n]

All these vehicles, including the Weasel and the DUKW, represent preliminary and very tentative attempts at solutions to the general problem of providing efficient means for crossing snow, mud, and quicksand. This study should be continued on the basis of a comprehensive and fundamental program covering all the factors involved in the design and use of low unit ground pressure vehicles.

The difficulties of the problem should be clearly recognized. In the consideration of a vehicle to be used in the Arctic, for example, it should be realized that most of the Arctic regions are physiographically very old, the rivers meander nearly at grade, the particle size is small, and the underwater gradient of the beaches is flat. In many parts of the Arctic during summer, it is impossible for men to get ashore on their own feet. The mud flats of regions of Hudson Bay, the mouth of the Mackenzie River, and various portions of the Siberian coast have such a high water content that they cannot be crossed on foot; they cannot, in fact, be crossed by the Weasel.

Similar difficulties would be involved in operating a vehicle over the muddy terrain of the mouth of the Mississippi, the Louisiana bayous, the Florida swamps, and other areas in the Gulf States.

It is the belief of the division and its contractors that improvements in the low unit ground pressure technique can be sought in the following general fields:

1. *Perfection and modification of existing equipment.* Such a program, which could well be carried out by Army Ordnance in collaboration with the automotive industry, would include such steps as modifications in existing models of the Weasel and the DUKW.

2. *Development of variations of existing equipment.* This type of investigation, which could well be conducted by a civilian organization such as the Stevens Institute of Technology, should be based on fundamental research into the problems surrounding low unit ground pressure and would include, for example, larger Weasels and DUKWs, as recommended in Chapters 4 and 5.

[j] See Section 10.3 in this chapter.
[k] See Chapter 5 in this volume.
[l] See Chapter 7 in this volume.
[m] See Chapter 3 in this volume.
[n] See Chapter 15 in this volume.

3. *Development of novel and radical solutions.* Two examples, cited not because it is felt that their practicality has been proved but merely because they indicate the type of approach involved, include the jet-propelled vehicles designed for assault across mud[o] and the vehicle designed with an ultra-soft, hydraulic-controlled suspension to enable it to leap obstacles.[p]

[o] See Section 10.3 in this chapter.
[p] See Chapter 15.

4. *Improved use of vehicles.* It appears that the value of almost any vehicle can be significantly increased by improvement in indoctrination, organization, training, operation, and maintenance.[q] This type of improvement should be sought not only for any new or improved vehicles which may be developed but also for vehicles already available.

[q] See Section 1.6 in Chapter 1.

Chapter 11

PONTON BRIDGE REACTIONS

Summary

At the request of the Engineer Board of the U. S. Army Corps of Engineers, an extended study was made of ponton bridges typical of those proposed for use in military operations. A relatively simple analytical method was developed for both continuous, unarticulated bridges and articulated bridges.* With the equations developed, it is possible to determine the bridge reactions to loads, and the shear and moment curves.[1]

11.1 REACTIONS OF CONTINUOUS PONTON BRIDGES

A continuous, unarticulated ponton bridge of any length may be considered as a *simple* beam supported at 0 (zero) and n (Figure 1). It may be investigated for

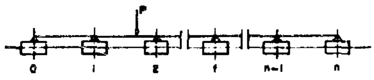


FIGURE 1. Continuous ponton bridge without articulation.

one or more loads acting downward and a series of generally upward forces, the reactions of the pontons, under all of which it must meet deflection conditions to give a consistent solution. Under load (Figure 2).

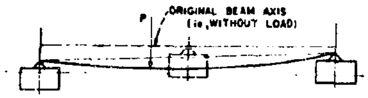


FIGURE 2. Ponton bridge with load.

the end pontons will go down and the assumed simple beam will deflect below the line joining the ends. At each interior ponton, a force will be applied which will lower that ponton, raise the end pontons, and cause the beam to deflect above the line joining the ends. The distance that a ponton goes down must therefore equal the difference between the amounts the corresponding point on the beam goes *down* due to the loads and *up* due to the ponton reactions.

For convenience it is assumed that the ponton reaction is a force at the center of the ponton and that all horizontal sections through the ponton have the same area. The displacement C per foot depth of ponton equals the product of this area (square feet) and 62.4 (pounds per cubic foot) and is expressed in pounds per foot.

Let a load P act at point b (distance kL from 0) on a beam length nL, supported by pontons at 0 and n (Figure 3). At a point a (distance fL from 0), it is de-

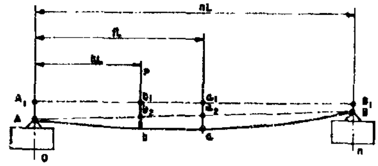


FIGURE 3. Reactions of ponton bridge.

sired to find a_1a_2, the distance that a point on AB, the straight line joining the beam ends, is below A_1B_1, the original unloaded position of the line. The portion of the load that goes to the ponton at 0 is

$$\frac{nL - kL}{nL}P,$$

and, therefore,

$$A_1A = \frac{n - k}{nC}P.$$

Similarly $$B_1B = \frac{kP}{nC}.$$

Then $$a_1a_2 = \frac{(n - k)P}{nC} - \frac{f}{n}\left[\frac{(n - k)P}{nC} - \frac{kP}{nC}\right]$$

$$= \frac{P}{nC}\left[(n - k) - \frac{f}{n}(n - 2k)\right]$$

$$= \frac{P}{nC}\left(n - k - f + \frac{2fk}{n}\right).$$

* This investigation was conducted by the Drexel Institute of Technology, Philadelphia, Pa., under OSRD contract OEMsr-11.

In the same way, an interior ponton reaction R at a distance xL from 0 will at a raise AB an amount

$$\frac{R}{nC}\left(n - x - f + \frac{2fx}{n}\right).$$

Next it is desired to find the distance a_2a (Figure 3) which P and R cause a to deflect from line AB. (The computation will be made by the "conjugate beam" method, but the same result would be obtained by any other method for computing deflections.) Load P causes the reactions and moment curve of Figures 4A and 4B. The conjugate beam and its load are shown in Figure 4C. Because of this load, the right reaction is

$$R_R = \frac{1}{2}nL\,\frac{PL\,k(n-k)}{EI\quad n}\,\frac{(n+k)L}{3nL}$$

$$= \frac{PL^2\,k(n^2-k^2)}{6EI\quad n}.$$

Then

$$a_2a = \frac{PL^2\,k(n^2-k^2)}{6EI\quad n}(n-f)L$$

$$-\frac{1}{2}(n-f)L\,\frac{PL\,k(n-f)}{EI\quad n}\,\frac{(n-f)L}{3}$$

$$= \frac{PL^3}{6EI}\left[\frac{k(n^2-k^2)(n-f)}{n} - \frac{k(n-f)^3}{n}\right]$$

$$= \frac{PL^3\,k(n-f)\left[(n^2-k^2)-(n-f)^2\right]}{6EI\quad n}$$

$$= \frac{PL^3\,k(n-f)(2nf-k^2-f^2)}{6EI\quad n}.$$

In the same way it may be shown that, if P is applied to the right of a,

$$a_2a = \frac{PL^3\,f(n-k)(2nk-f^2-k^2)}{6EI\quad n},$$

and if P is applied at a,

$$a_2a = \frac{PL^3\,2f^2(n-f)^2}{6EI\quad n}.$$

Similar upward deflections occur when the reaction R is applied to the left of a, to the right of a, and at a.

Finally, due to a reaction R, a ponton will go down a distance R/C.

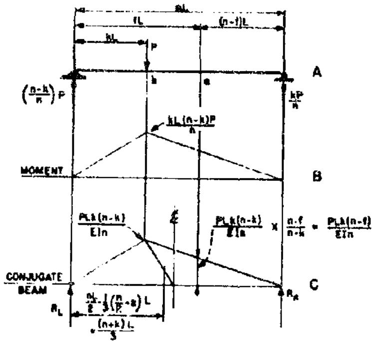


FIGURE 4. Reactions and moment curves.

If there is a ponton at a distance fL from 0 and this ponton has a reaction R_f,[6] then by using the values which were derived above, it is possible to write the following equation:

$\Sigma\frac{P}{nC}\left[n-k-f+\frac{2fk}{n}\right]$	[A term for each load.]
$+\Sigma\frac{PL^3\,k(n-f)(2nf-k^2-f^2)}{6EI\quad n}$	[A term for each load applied to the left of f]
$+\frac{PL^3\,2f^2(n-f)^2}{6EI\quad n}$	[A term if a load is applied at f.]
$+\Sigma\frac{PL^3\,f(n-k)(2nk-f^2-k^2)}{6EI\quad n}$	[A term for each load applied to the right of f.]
$-\Sigma\frac{R_x}{nC}\left[n-x-f+\frac{2fx}{n}\right]$	[A term for each interior ponton including f]
$-\Sigma\frac{R_xL^3\,x(n-f)(2nf-x^2-f^2)}{6EI\quad n}$	[A term for each interior ponton to the left of f]
$-\frac{R_fL^3\,2f^2(n-f)^2}{6EI\quad n}$	[One term]
$-\Sigma\frac{R_xL^3\,f(n-x)(2nx-f^2-x^2)}{6EI\quad n}$	[A term for each interior ponton to the right of f]
$-\frac{R_f}{C}$	[One term]

[6] A subscript (for example, x) after a ponton reaction indicates that the ponton is at a distance xL from 0.

For convenience in computing, multiply all of the foregoing terms by nC and let

$$\frac{CL^3}{6EI} = H.$$

In any case the solution will be made for a known load or loads in a fixed position. Hence the terms containing P will be known numbers, and the unknowns in the equation will be the interior ponton reactions. By placing all unknowns to the left of the equals sign, it is possible to write the following equation:

$$\Sigma R_s\left[n - s - f + \frac{2fs}{n}\right] \quad \left[\text{A term (1) for each interior ponton, including } f\right]$$

$$+ \Sigma R_s H\{s(n-f)(2nf - s^2 - f^2)\} \quad \left[\text{A term (2) for each interior ponton to the left of } f.\right]$$

$$+ R_f H\{2f^2(n-f)^2\} \quad \{\text{One term (3)}\}$$

$$+ nR_f \quad \{\text{One term (4).}\}$$

$$+ \Sigma\{R_s H f(n-s)(2ns - f^2 - s^2)\} \quad \left[\text{A term (5) for each interior ponton to the right of } f.\right]$$

$$= \Sigma P\left[n - k - f + \frac{2fk}{n}\right] \quad \left[\text{A term (6) for each load}\right]$$

$$+ \Sigma PH\{k(n-f)(2nf - k^2 - f^2)\} \quad \left[\text{A term (7) for each load applied to the left of } f.\right]$$

$$+ PH\{2f^2(n-f)^2\} \quad \left[\text{A term (8) if a load is applied at } f\right]$$

$$+ \Sigma PH\{f(n-k)(2nk - f^2 - k^2)\}. \quad \left[\text{A term (9) for each load applied to the right of } f.\right]$$

Just as the foregoing equation has been written for the ponton reaction of f, a similar equation may be written for every interior ponton. This will give a group of equations in which there are as many unknowns as there are interior pontons. Since there will be this same number of equations, a solution of these simultaneous equations will give the numerical values of the interior ponton reactions. Following this, the values of the ponton reactions at 0 and n may be found by statics, and the shear and moment curves may be drawn for the structure.

11.1.4 **Solution of Equations**

A number of examples are solved here to show the application of the method.

Example 1. Find the reactions and draw the shear and moment curves for the structure and load shown in Figure 5.

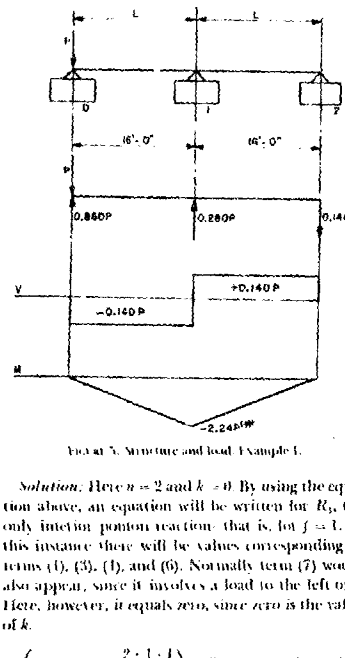


FIGURE 5. Structure and load, Example 1.

Solution: Here $n = 2$ and $k = 0$. By using the equation above, an equation will be written for R_1, the only interior ponton reaction—that is, for $f = 1$. In this instance there will be values corresponding to terms (1), (3), (4), and (6). Normally term (7) would also appear, since it involves a load to the left of f. Here, however, it equals zero, since zero is the value of k.

$$R_1\left(2 - 1 - 1 + \frac{2\cdot 1\cdot 1}{2}\right) + R_1H(2\cdot 1^2\cdot 1^2) + 2R_1 = P\left(2 - 0 - 1 + \frac{2\cdot 1\cdot 0}{2}\right).$$

$$R_1 + 2HR_1 + 2R_1 = P.$$

$$3R_1 + 2HR_1 = P.$$

This is as far as the solution can be carried until a value is assigned to H. The following will be assumed:

$L = 16$ ft.

$E = 1{,}500{,}000$ p.s.i.

$$I = 11\left[\frac{1}{12} \cdot 5\frac{3}{16} \cdot \left(7\frac{3}{4}\right)^3\right] = 2{,}211 \text{ in.}^4.$$

$$C = 160 \text{ sq ft} \cdot 62.4 \text{ lb per cu ft} = 10{,}000 \text{ lb per ft.}$$

$$\text{Then } H = \frac{CL^3}{6EI} = \frac{10{,}000 \cdot 16^3}{6 \cdot 1{,}500{,}000 \cdot 12^2 \cdot \frac{2211}{12^4}}$$

$$= 0.296.$$

Note that it has been necessary to express E and I in foot units since C and L are in foot units; also that H is a dimensionless number—that is, all units cancel.

$$\frac{\frac{\text{lb}}{\text{ft}} \cdot \text{ft}^3}{\frac{\text{lb}}{\text{ft}^2} \cdot \text{ft}^4}.$$

$$3R_1 + 2(0.296)R_1 = P$$

$$R_1 = \frac{P}{3.592} = 0.280\, P \uparrow$$

By $\Sigma M = 0$ about 0, $R_2 = 0.140\, P \downarrow$ (*i.e., down*)

By $\Sigma V = 0$ $\qquad R_0 = 0.860\, P \uparrow$

Example 2. Solve the structure of the previous example when the load is placed at the middle of the first span as in Figure 6.

Solution: For every two-span structure, the left side of the equation is constant. Now, $k = 1/2$. Therefore—

$$3.592\, R_1 = P\left[2 - \tfrac{1}{2} - 1 + \frac{2 \cdot 1 \cdot \tfrac{1}{2}}{2}\right] + PH\left[\tfrac{1}{2}(2-1)(2 \cdot 2 \cdot 1 - \tfrac{1}{4} - 1)\right]$$

$$= P + \frac{11}{8}HP$$

$$= P + \frac{11}{8}(0.296)P$$

$$= 1.407\, P.$$

$$\therefore \quad R_1 = 0.392\, P.$$

$$R_2 = 0.054\, P.$$

$$R_0 = 0.554\, P.$$

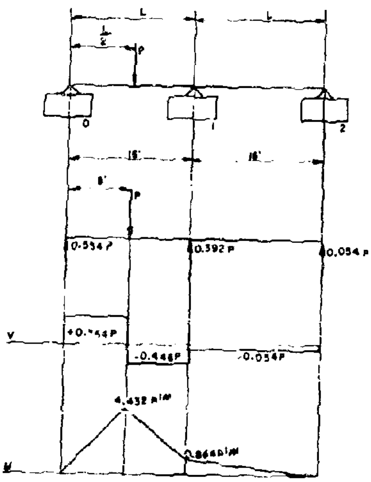


FIGURE 6. Structure and load, Example 2

Example 3. Solve the structure of the previous example when the load is placed over the center ponton as in Figure 7.

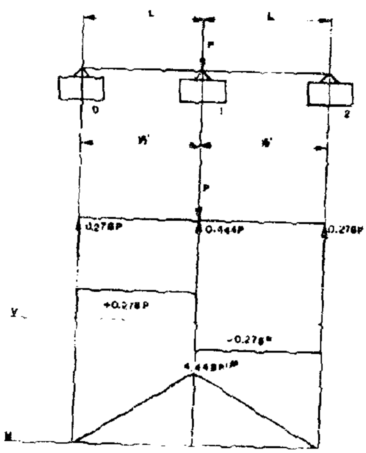


FIGURE 7. Structure and load, Example 3

Solution: Here $k = 1$. Therefore,

$$3.592\,R_1 = P\left(2 - 1 - 1 + \frac{2 \cdot 1 \cdot 1}{2}\right) + PH\,[2 \cdot 1^2\,(2 - 1)^2]$$

$$= P + 2HP$$

$$= 1.592\,P.$$

$$\therefore \quad R_1 = 0.444\,P.$$

$$R_0 = R_2 = 0.278\,P.$$

Example 4. Find the reactions and draw the shear and moment curves for the structure and load shown in Figure 8. Assume that H has the same value as in the previous examples.

Solution: Here two equations must be written, one for $f = 1$ and the other for $f = 2$. For $f = 1$

$$R_1\left[3 - 1 - 1 + \frac{2 \cdot 1 \cdot 1}{3}\right] + R_2\left[3 - 2 - 1 + \frac{2 \cdot 1 \cdot 2}{3}\right] + R_1H\,[2 \cdot 1^2(3 - 1)^2] + 3R_1 + R_2H\,[1(3 - 2)\,(2 \cdot 3 \cdot 2 - 1^2 - 2^2)] = P\left[3 - 0 - 1 + \frac{2 \cdot 1 \cdot 0}{3}\right].$$

$$\frac{5}{3}R_1 + \frac{4}{3}R_2 + 8HR_1 + 3R_1 + 7HR_2 = 2P.$$

$$\frac{14}{3}R_1 + 8HR_1 + \frac{4}{3}R_2 + 7HR_2 = 2P. \qquad (1)$$

For $f = 2$

$$R_1\left[3 - 1 - 2 + \frac{2 \cdot 2 \cdot 1}{3}\right] + R_2\left[3 - 2 - 2 + \frac{2 \cdot 2 \cdot 2}{3}\right] + R_1H\,[1(3 - 2)\,(2 \cdot 3 \cdot 2 - 1^2 - 2^2)] + R_2H\,[2 \cdot 2^2(3 - 2)^2] + 3R_2 = P\left(3 - 0 - 2 + \frac{2 \cdot 2 \cdot 0}{3}\right).$$

$$\frac{4}{3}R_1 + \frac{5}{3}R_2 + 7HR_1 + 8HR_2 + 3R_2 = P. \qquad (2)$$

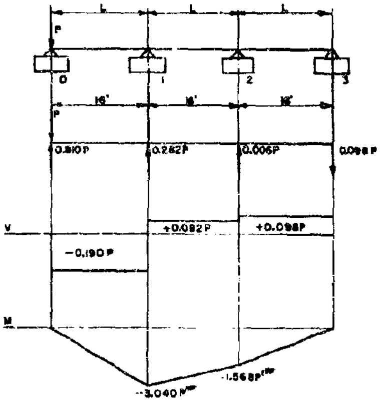


FIGURE 8. Structure and load Example 4.

Therefore, since $H = 0.296$

$$7.035\,R_1 + 3.405\,R_2 = 2P. \qquad (1')$$

$$3.405\,R_1 + 7.035\,R_2 = P. \qquad (2')$$

$$7.035\,R_1 + 14.500\,R_2 = 2.064\,P. \qquad (2'')$$

$$11.095\,R_2 = 0.064\,P \qquad (2'' - 1')$$

$$R_2 = 0.006\,P.$$

$$7.035\,R_1 + 3.405\,(0.006)P = 2P.$$

$$R_1 = 0.282\,P.$$

The values of R_0 and R_3 may be found by use of the equations $\Sigma M = 0$ and $\Sigma V = 0$.

Example 5. Find the reactions and draw the shear and moment curves for the five-span structure due to two loads as shown in Figure 9

Solution. The complete solution is shown on the insert with Figure 9. Note that in the section labeled *Formation of Equations*, there are four areas which are bounded by heavy solid lines. The computation within these areas relates to *every* regular five-span structure and need never be made again. Furthermore, in this same section there are four areas and in the section *Solution of Equations* another area—all bounded by heavy dashed lines. This much of the

1

SOLUTION OF EQUATIONS							
Eq.		R_1	R_2	R_3	R_4	= Absolute + 10	Check
	1	17.87	16.12	14.04	8.41	30.83	87.27
	2	16.12	28.91	22.53	14.04	43.40	125.01
	3	14.04	27.53	28.91	16.12	39.95	121.55
	4	8.41	14.04	16.12	17.87	24.61	81.05
	1'	1	0.902	0.787	0.472	1.725	4.886
	2'	1	1.794	1.398	0.872	2.693	7.757
	3'	1	1.605	2.060	1.148	2.846	8.659
	4'	1	1.670	1.917	2.126	2.926	9.599
2' − 1'	a		0.892	0.611	0.400	0.968	2.871
3' − 1'	b		0.705	1.273	0.676	1.121	3.775
4' − 1'	c		0.768	1.130	1.654	1.201	4.753
	a'		1	0.685	0.448	1.086	3.219
	b'		1	1.811	0.952	1.595	[illegible]
	c'		1	1.472	2.155	1.564	[illegible]
b' − a'	d			1.126	0.514	0.509	2.149
c' − a'	e			0.787	1.705	0.478	2.970
	d'			1	0.456	0.452	1.908
	e'			1	2.167	0.607	3.774
e' − d'	f				1.711	0.155	1.866
	f'				1	0.091	1.091

$n = 5$

$k_{12} = \frac{3}{2}$

$k_4 = \frac{19}{8}$

$H = 0.[illegible]96$

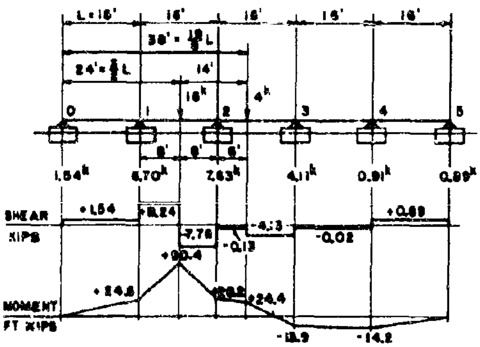


Figure 9

Eq.	R_1	R_2	R_3	R_4	= Absolute + 10
d'			$\bar{R}_3$ R_4	+ 0.041	0.452 0.411
a'		R_2 R_2	+ 0.282	+ 0.041	1.086 0.763
1'	R_1 R_1	+ 0.686	+ 0.324	+ 0.043	1.725 0.670

Check
87.27 125.01 121.55 81.05
4.886 7.757 8.659 9.589
2.871 3.775 4.755
3.219 5.36[illegible] [illegible]
2.149 2.970
1.908 3.774
1.866 1.091

FORMATION

Equation 1.	$R_1\left(5-1-1+\frac{2\cdot1\cdot1}{5}\right)$ [= $3.4R_1$] $+R_1H(2\cdot1\cdot16)$ [= $32HR_1$] $+5R_1$ [= $5R_1$]	$+R_2\left(5-2-1+\frac{2\cdot1\cdot2}{5}\right)$ [= $2.8R_2$] $+R_2H[1\cdot3(2\cdot5\cdot2-1-4)]$ [= $45HR_2$]	$+R_3(5-3-1+$ $+R_3H[1\cdot2(2\cdot5\cdot$
	$+8.4R_1+32HR_1$	$+2.8R_2+45HR_2$	$+2$
	$+17.87R_1$	$+16.12R_2$	
Equation 2.	$R_1\left(5-1-2+\frac{2\cdot2\cdot1}{5}\right)$ [= $2.8R_1$] $+R_1H[1\cdot3(2\cdot5\cdot2-1-4)]$ [= $45HR_1$]	$+R_2\left(5-2-2+\frac{2\cdot2\cdot2}{5}\right)$ [= $2.6R_2$] $+R_2H(2\cdot4\cdot9)$ [= $72HR_2$] $+5R_2$ [= $5R_2$]	$+R_3(5-3-2+$ $+R_3H[2\cdot2(2\cdot5$
	$+2.8R_1+45HR_1$	$+7.6R_2+72HR_2$	$+2$
	$+16.12R_1$	$+28.91R_2$	
Equation 3.	$R_1\left(5-1-3+\frac{2\cdot3\cdot1}{5}\right)$ [= $2.2R_1$] $+R_1H[1\cdot2(2\cdot5\cdot3-1-9)]$ [= $40HR_1$]	$+R_2\left(5-2-3+\frac{2\cdot3\cdot2}{5}\right)$ [= $2.4R_2$] $+R_2H[2\cdot2(2\cdot5\cdot3-4-9)]$ [= $68HR_2$]	$+R_3(5-3-3$ $+R_3H(2\cdot9\cdot4)$ $+5R_3$
	$+2.2R_1+40HR_1$	$+2.4R_2+68HR_2$	$+$
	$+14.04R_1$	$+22.53R_2$	
Equation 4.	$R_1\left(5-1-4+\frac{2\cdot4\cdot1}{5}\right)$ [= $1.6R_1$] $+R_1H[1\cdot1(2\cdot5\cdot4-1-16)]$ [= $23HR_1$]	$+R_2\left(5-2-4+\frac{2\cdot4\cdot2}{5}\right)$ [= $2.2R_2$] $+R_2H[2\cdot1(2\cdot5\cdot4-4-16)]$ [= $40HR_2$]	$+R_3(5-3-4$ $+R_3H[3\cdot1(2\cdot$
	$+1.6R_1+23HR_1$	$+2.2R_2+40HR_2$	$+$
	$+8.41R_1$	$+14.04R_2$	

UTION OF EQUATIONS

R_2	R_3	R_4	Absolute + 10	Check	
6.12 8.91 2.53 1.04	14.04 22.53 28.91 10.12	8.41 14.04 16.12 17.87	30.83 45.40 39.95 24.61	87.27 125.01 121.55 81.05	Equation 1.
0.902 1.794 1.605 1.670	0.787 1.508 2.060 1.917	0.472 0.872 1.148 2.126	1.725 2.695 2.846 2.926	4.886 7.757 8.659 9.639	
0.892 0.705 0.768	0.611 1.275 1.150	0.400 0.676 1.654	0.968 1.121 1.201	2.871 3.773 4.755	Equation 2.
1 1 1	0.685 1.811 1.472	0.448 0.962 2.155	1.086 1.595 1.564	3.219 5.368 6.189	
	1.126 0.787	0.514 1.705	0.509 0.478	2.149 2.970	
	1 1	0.456 2.167	0.452 0.607	1.908 3.774	Equation 3.
		1.711 1	0.155 0.091	1.866 1.091	

R_2	R_3	R_4	Absolute + 10	
	R_3 R_3	+ 0.041	0.452 0.411	
R_2 R_2	+ 0.282	+ 0.041	1.086 0.763	
0.688	+ 0.324	+ 0.043	1.725 0.670	Equation 4.

2

Check
37.27 25.01 21.55 31.05
4.886 7.757 8.659 9.639
2.871 3.773 4.753
3.219 5.368 6.189
2.149 2.970
1.908 3.774
1.866 1.081

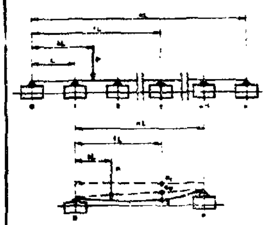
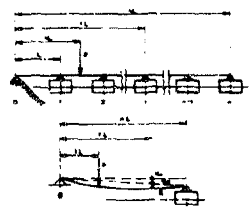
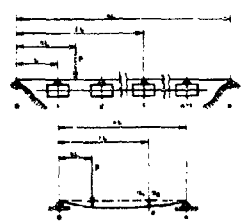
FORMATION OF EQUATIONS

Equation 1.	$R_1\left(5-1-1+\frac{2\cdot1\cdot1}{5}\right)$ [$=3.4R_1$] $+R_1H(2\cdot1\cdot16)$ [$=32HR_1$] $+5R_1$ [$=5R_1$]	$+R_2\left(5-2-1+\frac{2\cdot1\cdot2}{5}\right)$ [$=2.8R_2$] $+R_2H[1\cdot3(2\cdot5\cdot2-1-4)]$ [$=45HR_2$]	$+R_3\left(5-3-1+\frac{2\cdot1\cdot3}{5}\right)$ [$=2.2R_3$] $+R_3H[1\cdot2(2\cdot5\cdot3-1-9)]$ [$=40HR_3$]	$+R_4\left(5-4-1+\frac{2\cdot1\cdot4}{5}\right)$ [$=1.6R_4$] $+R_4H[1\cdot1(2\cdot5\cdot4-1-16)]$ [$=23HR_4$]		$16\left(5-\frac{3}{2}-1+\frac{2\cdot1\cdot\frac{3}{2}}{5}\right)$ [$=49.6$] $+16H\left(1\cdot\frac{7}{2}\right)\left(2\cdot5\cdot\frac{3}{2}-1-\frac{9}{4}\right)$ [$=658H$] $+4\left(5-\frac{19}{8}-1+\frac{2\cdot1\cdot\frac{19}{8}}{5}\right)$ [$=10.3$] $+4H\left[1\cdot\frac{21}{8}\left(2\cdot5\cdot\frac{19}{8}-1-\frac{361}{64}\right)\right]$ [$=180H$]
	$+8.4R_1+32HR_1$	$+2.8R_2+45HR_2$	$+2.2R_3+40HR_3$	$+1.6R_4+23HR_4$	=	$59.9+838H$
	$+17.87R_1$	$+16.12R_2$	$+14.04R_3$	$+8.41R_4$	=	308.5
Equation 2.	$R_1\left(5-1-2+\frac{2\cdot2\cdot1}{5}\right)$ [$=2.8R_1$] $+R_1H[1\cdot3(2\cdot5\cdot2-1-4)]$ [$=45HR_1$]	$+R_2\left(5-2-2+\frac{2\cdot2\cdot2}{5}\right)$ [$=2.6R_2$] $+R_2H(2\cdot4\cdot9)$ [$=72HR_2$] $+5R_2$ [$=5R_2$]	$+R_3\left(5-3-2+\frac{2\cdot2\cdot3}{5}\right)$ [$=2.4R_3$] $+R_3H[2\cdot2(2\cdot5\cdot3-4-9)]$ [$=68HR_3$]	$+R_4\left(5-4-2+\frac{2\cdot2\cdot4}{5}\right)$ [$=2.2R_4$] $+R_4H[2\cdot1(2\cdot5\cdot4-4-16)]$ [$=40HR_4$]		$16\left(5-\frac{3}{2}-2+\frac{2\cdot2\cdot\frac{3}{2}}{5}\right)$ [$=43.2$] $+16H\left[\frac{3}{2}\cdot3\left(2\cdot5\cdot2-\frac{9}{4}-4\right)\right]$ [$=990H$] $+4\left(5-\frac{19}{8}-2+\frac{2\cdot2\cdot\frac{19}{8}}{5}\right)$ [$=10.1$] $+4H\left[2\cdot\frac{21}{8}\left(2\cdot5\cdot\frac{19}{8}-4-\frac{361}{64}\right)\right]$ [$=296H$]
	$+2.8R_1+45HR_1$	$+7.6R_2+72HR_2$	$+2.4R_3+68HR_3$	$+2.2R_4+40HR_4$	=	$53.3+1296H$
	$+16.12R_1$	$+28.91R_2$	$+22.53R_3$	$+14.04R_4$	=	434.0
Equation 3.	$R_1\left(5-1-3+\frac{2\cdot3\cdot1}{5}\right)$ [$=2.2R_1$] $+R_1H[1\cdot2(2\cdot5\cdot3-1-9)]$ [$=40HR_1$]	$+R_2\left(5-2-3+\frac{2\cdot3\cdot2}{5}\right)$ [$=2.4R_2$] $+R_2H[2\cdot2(2\cdot5\cdot3-4-9)]$ [$=68HR_2$]	$+R_3\left(5-3-3+\frac{2\cdot3\cdot3}{5}\right)$ [$=2.6R_3$] $+R_3H(2\cdot9\cdot4)$ [$=72HR_3$] $+5R_3$ [$=5R_3$]	$+R_4\left(5-4-3+\frac{2\cdot3\cdot4}{5}\right)$ [$=2.8R_4$] $+R_4H[3\cdot1(2\cdot5\cdot4-9-16)]$ [$=45HR_4$]		$16\left(5-\frac{3}{2}-3+\frac{2\cdot3\cdot\frac{3}{2}}{5}\right)$ [$=36.8$] $+16H\left[\frac{3}{2}\cdot2\left(2\cdot5\cdot3-\frac{9}{4}-9\right)\right]$ [$=900H$] $+4\left(5-\frac{19}{8}-3+\frac{2\cdot3\cdot\frac{19}{8}}{5}\right)$ [$=9.9$] $+4H\left[\frac{19}{8}\cdot2\left(2\cdot5\cdot3-9-\frac{361}{64}\right)\right]$ [$=292H$]
	$+2.2R_1+40HR_1$	$+2.4R_2+68HR_2$	$+7.6R_3+72HR_3$	$+2.8R_4+45HR_4$	=	$46.7+1192H$
	$+14.04R_1$	$+22.53R_2$	$+28.91R_3$	$+16.12R_4$	=	399.5
Equation 4.	$R_1\left(5-1-4+\frac{2\cdot4\cdot1}{5}\right)$ [$=1.6R_1$] $+R_1H[1\cdot1(2\cdot5\cdot4-1-16)]$ [$=23HR_1$]	$+R_2\left(5-2-4+\frac{2\cdot4\cdot2}{5}\right)$ [$=2.2R_2$] $+R_2H[2\cdot1(2\cdot5\cdot4-4-16)]$ [$=40HR_2$]	$+R_3\left(5-3-4+\frac{2\cdot4\cdot3}{5}\right)$ [$=2.8R_3$] $+R_3H[3\cdot1(2\cdot5\cdot4-9-16)]$ [$=45HR_3$]	$+R_4\left(5-4-4+\frac{2\cdot4\cdot4}{5}\right)$ [$=3.4R_4$] $+R_4H(2\cdot16\cdot1)$ [$=32HR_4$] $+5R_4$ [$=5R_4$]		$16\left(5-\frac{3}{2}-4+\frac{2\cdot4\cdot\frac{3}{2}}{5}\right)$ [$=30.4$] $+16H\left[\frac{3}{2}\cdot1\left(2\cdot5\cdot4-\frac{9}{4}-16\right)\right]$ [$=522H$] $+4\left(5-\frac{19}{8}-4+\frac{2\cdot4\cdot\frac{19}{8}}{5}\right)$ [$=9.7$] $+4H\left[\frac{19}{8}\cdot1\left(2\cdot5\cdot4-16-\frac{361}{64}\right)\right]$ [$=174H$]
	$+1.6R_1+23HR_1$	$+2.2R_2+40HR_2$	$+2.8R_3+45HR_3$	$+8.4R_4+32HR_4$	=	$40.1+696H$
	$+8.41R_1$	$+14.04R_2$	$+16.12R_3$	$+17.87R_4$	=	246.1

CONFIDENTIAL

Reactions of Ponton Bridges (without articulation)

METHOD OF SOLUTION: Letting f vary from 1 to $n-1$, write one equation of the form shown above for every interior reaction. The unknowns in these equations will be the values of the interior reactions and there will be as many equations as there are unknowns. Solve this set of simultaneous equations for the values of the interior reactions. Then use the equations $\Sigma M = 0$ and $\Sigma Y = 0$ to determine the end reactions. With *all* reactions known, shears and moments may be found throughout the structure.

Case I. Both ends on pontons.	Case II. One end on a fixed support.	Case III. Both ends on fixed supports.
 Figure 10	 Figure 11	 Figure 12

Consider a bridge of any length as a *simple* beam supported at 0 and n. Due to a load P applied at a distance kL from 0, a straight line joining the beam ends will, at a distance fL from 0, be an amount a_1a_2 below the reference line (i.e., the original position of the beam). (C is the load to cause a ponton to settle a unit distance.)

In like manner, an interior ponton reaction, R_x, at a distance xL from 0 will cause an upward motion a_1a_2.

Due to a load P at a distance kL from 0, there will be a deflection a_2a below the straight line joining the beam ends and at a distance fL from 0: If $k < f$; If $k = f$; If $k > f$.

Similarly, a ponton reaction R will cause a deflection a_2a at a distance fL from 0: If R_s is the reaction and sL its distance from 0 where $s < f$; If R_f is the reaction and fL its distance from 0; If R_r is the reaction and rL its distance from 0 where $r > f$.

Also, under a reaction R_f, the ponton at a distance fL from 0 will go down a distance δ.

	Case I	Case II	Case III
a	$a_1a_2 = \frac{P}{Cn}\left(n-k-f+\frac{2fk}{n}\right)$	$a_1a_2 = \frac{Pfk}{Cn^2}$	$a_1a_2 = 0$
b	$a_1a_2 = \frac{R_x}{Cn}\left(n-x-f+\frac{2fx}{n}\right)$	$a_1a_2 = \frac{R_xfx}{Cn^2}$	$a_1a_2 = 0$
c	$a_2a = \frac{PL^3}{6EI}\left[\frac{k(n-f)(2nf-k^2-f^2)}{n}\right]$	$a_2a = \frac{PL^3}{6EI}\left[\frac{k(n-f)(2nf-k^2-f^2)}{n}\right]$	$a_2a = \frac{PL^3}{6EI}\left[\frac{k(n-f)(2nf-k^2-f^2)}{n}\right]$
d	$a_2a = \frac{PL^3}{6EI}\left[\frac{2f^2(n-f)^2}{n}\right]$	$a_2a = \frac{PL^3}{6EI}\left[\frac{2f^2(n-f)^2}{n}\right]$	$a_2a = \frac{PL^3}{6EI}\left[\frac{2f^2(n-f)^2}{n}\right]$
e	$a_2a = \frac{PL^3}{6EI}\left[\frac{(n-k)f(2nk-k^2-f^2)}{n}\right]$	$a_2a = \frac{PL^3}{6EI}\left[\frac{(n-k)f(2nk-k^2-f^2)}{n}\right]$	$a_2a = \frac{PL^3}{6EI}\left[\frac{(n-k)f(2nk-k^2-f^2)}{n}\right]$
f	$a_2a = \frac{R_sL^3}{6EI}\left[\frac{s(n-f)(2nf-s^2-f^2)}{n}\right]$	$a_2a = \frac{R_sL^3}{6EI}\left[\frac{s(n-f)(2nf-s^2-f^2)}{n}\right]$	$a_2a = \frac{R_sL^3}{6EI}\left[\frac{s(n-f)(2nf-s^2-f^2)}{n}\right]$
g	$a_2a = \frac{R_fL^3}{6EI}\left[\frac{2f^2(n-f)^2}{n}\right]$	$a_2a = \frac{R_fL^3}{6EI}\left[\frac{2f^2(n-f)^2}{n}\right]$	$a_2a = \frac{R_fL^3}{6EI}\left[\frac{2f^2(n-f)^2}{n}\right]$
h	$a_2a = \frac{R_rL^3}{6EI}\left[\frac{f(n-r)(2nr-r^2-f^2)}{n}\right]$	$a_2a = \frac{R_rL^3}{6EI}\left[\frac{f(n-r)(2nr-r^2-f^2)}{n}\right]$	$a_2a = \frac{R_rL^3}{6EI}\left[\frac{f(n-r)(2nr-r^2-f^2)}{n}\right]$
i	$\delta = \frac{R_f}{C}$	$\delta = \frac{R_f}{C}$	$\delta = \frac{R_f}{C}$

Now $\Sigma a + \Sigma c + d + \Sigma e - \Sigma b - \Sigma f - g - \Sigma h = i$
or, $\Sigma b + \Sigma f + g + \Sigma h + i = \Sigma a + \Sigma c + d + \Sigma e$

That is, as f varies from 1 to $n-1$ there will be:

	Case I	Case II	Case III
a′ A term like this for every reaction, including f.	$\sum\frac{R_x}{Cn}\left(n-x-f+\frac{2fx}{n}\right)$	$\sum\frac{R_xfx}{Cn^2}$	———
b′ A term like this for every interior reaction to the left of f, distance sL from 0.	$+\sum\frac{R_sL^3}{6EI}\left[\frac{s(n-f)(2nf-s^2-f^2)}{n}\right]$	$+\sum\frac{R_sL^3}{6EI}\left[\frac{s(n-f)(2nf-s^2-f^2)}{n}\right]$	$\sum\frac{R_sL^3}{6EI}\left[\frac{s(n-f)(2nf-s^2-f^2)}{n}\right]$
c′ One term like this.	$+\frac{R_fL^3}{6EI}\left[\frac{2f^2(n-f)^2}{n}\right]$	$+\frac{R_fL^3}{6EI}\left[\frac{2f^2(n-f)^2}{n}\right]$	$+\frac{R_fL^3}{6EI}\left[\frac{2f^2(n-f)^2}{n}\right]$
d′ One term like this.	$+\frac{R_f}{C}$	$+\frac{R_f}{C}$	$+\frac{R_f}{C}$
e′ A term like this for every interior reaction to the right of f, distance rL from 0.	$+\sum\frac{R_rL^3}{6EI}\left[\frac{f(n-r)(2nr-r^2-f^2)}{n}\right]$	$+\sum\frac{R_rL^3}{6EI}\left[\frac{f(n-r)(2nr-r^2-f^2)}{n}\right]$	$+\sum\frac{R_rL^3}{6EI}\left[\frac{f(n-r)(2nr-r^2-f^2)}{n}\right]$
f′ A term like this for each load.	$-\sum\frac{P}{Cn}\left(n-k-f+\frac{2fk}{n}\right)$	$-\sum\frac{Pfk}{Cn^2}$	$-$ ———
g′ A term like this for each load for which $k < f$.	$+\sum\frac{PL^3}{6EI}\left[\frac{k(n-f)(2nf-k^2-f^2)}{n}\right]$	$+\sum\frac{PL^3}{6EI}\left[\frac{k(n-f)(2nf-k^2-f^2)}{n}\right]$	$\sum\frac{PL^3}{6EI}\left[\frac{k(n-f)(2nf-k^2-f^2)}{n}\right]$
h′ A term like this for a load $k = f$.	$+\frac{PL^3}{6EI}\left[\frac{2f^2(n-f)^2}{n}\right]$	$+\frac{PL^3}{6EI}\left[\frac{2f^2(n-f)^2}{n}\right]$	$+\frac{PL^3}{6EI}\left[\frac{2f^2(n-f)^2}{n}\right]$
i′ A term like this for each load for which $k > f$.	$+\sum\frac{PL^3}{6EI}\left[\frac{(n-k)f(2nk-k^2-f^2)}{n}\right]$	$+\sum\frac{PL^3}{6EI}\left[\frac{(n-k)f(2nk-k^2-f^2)}{n}\right]$	$+\sum\frac{PL^3}{6EI}\left[\frac{(n-k)f(2nk-k^2-f^2)}{n}\right]$

Multiply all terms by Cn and let $H = \frac{CL^3}{6EI}$.

Finally, there will be:

	Case I	Case II	Case III
a″ A term like this for every reaction, including f.	$\sum R_x\left(n-x-f+\frac{2fx}{n}\right)$	$\sum\frac{R_xfx}{n}$	———
b″ A term like this for every reaction to the left of f, distance sL from 0.	$+\sum R_sH[s(n-f)(2nf-s^2-f^2)]$	$+\sum R_sH[s(n-f)(2nf-s^2-f^2)]$	$\sum R_sH[s(n-f)(2nf-s^2-f^2)]$
c″ One term like this.	$+R_fH[2f^2(n-f)^2]$	$+R_fH[2f^2(n-f)^2]$	$+R_fH[2f^2(n-f)^2]$
d″ One term like this.	$+R_fn$	$+R_fn$	$+R_fn$
e″ A term like this for every interior reaction to the right of f, distance rL from 0.	$+\sum R_rH[f(n-r)(2nr-r^2-f^2)]$	$+\sum R_rH[f(n-r)(2nr-r^2-f^2)]$	$+\sum R_rH[f(n-r)(2nr-r^2-f^2)]$
f″ A term like this for each load.	$-\sum P\left(n-k-f+\frac{2fk}{n}\right)$	$-\sum\frac{Pfk}{n}$	$-$ ———
g″ A term like this for each load for which $k < f$.	$+\sum PH[k(n-f)(2nf-k^2-f^2)]$	$+\sum PH[k(n-f)(2nf-k^2-f^2)]$	$\sum PH[k(n-f)(2nf-k^2-f^2)]$
h″ A term like this for a load $k = f$.	$+PH[2f^2(n-f)^2]$	$+PH[2f^2(n-f)^2]$	$+PH[2f^2(n-f)^2]$
i″ A term like this for each load for which $k > f$.	$+\sum PH[(n-k)f(2nk-k^2-f^2)]$	$+\sum PH[(n-k)f(2nk-k^2-f^2)]$	$+\sum PH[(n-k)f(2nk-k^2-f^2)]$

sheet relates to this particular structure and is independent of the load. In other words, to investigate a structure for an additional position of the loads would necessitate the repetition of perhaps one-third of the work represented by this figure.[e]

The foregoing equations cover the situation in which all support is furnished by pontons. There are two other situations, however, that occur frequently—one in which one end of the structure is on an unyielding support, and another in which both ends are on such supports. The equations for all three of these cases are given on the insert with Figures 10, 11, and 12.

It should be noted that the derivations obtained here are based on the following assumptions:

1. The balk act as continuous beams.
2. The support at a ponton may be considered as a point support.
3. The righting moment due to the rotation of a ponton may be neglected.
4. Ponton displacement and ponton reaction are directly proportional to each other.

11.2 REACTIONS OF ARTICULATED PONTON BRIDGES

For certain combinations of ponton properties and bridge stiffnesses, it has been found necessary to permit an amount of articulation in the joints between the rafts which make up the structure. The joints are so arranged that some degree of motion must take place before they can transmit moment. Frequently the arrangement is such that the joints transmit no moment or, when closed, positive moment, but are unable under any condition to transmit negative moment.

The three-raft structure in Figure 13 may be considered as an example. Figure 13A shows the structure without load. If a small load P is placed over the center raft, that raft will be displaced downward (Figure 13B), but the adjoining rafts will simply rotate without supporting any considerable load. This rotation will continue until the joints between the rafts lock.

Until this locking occurs, the outer reactions equal zero. Any further load will be shared in some ratio among the three reactions.

For convenience, the sketch of Figure 13C will be considered equivalent to that of Figure 13B, except that in Figure 13C it is assumed that the load has been increased until the joints lock (d_2 still equals zero). This will give the maximum reaction R_{1m} which one raft alone can support. As shown, the elastic curve of the structure will have at the joints an abrupt angle a. The magnitude of this angle, or the amount of articulation, will depend on the construction.

As before, let L equal the raft length in feet and C the displacement of a ponton or raft in pounds per foot. In Figure 13C, it will be seen that the center ponton has been submerged an amount $CaL/2$, for which the symbol K will be used. Hence,

$$P_{1m} = R_{1m} = \frac{CaL}{2} = K.$$

Seven Rafts Acting, Maximum

A number of additional structures may now be investigated for a single center load. The greatest odd number of rafts acting will be taken as seven, that is, a nine-raft structure with the outer reactions equal to zero. From the center, the reactions for this case will be designated R_{1-7m}, R_{2-7m}, etc. (See Figure 14.) By the geometry of the figure, it may be shown that due to an angle of articulation a, the amounts by which successive points of reaction in each joint lie above the point of reaction at the center are, as indicated on line XX, $aL/2$, $4aL/2$, $9aL/2$, and $16aL/2$.

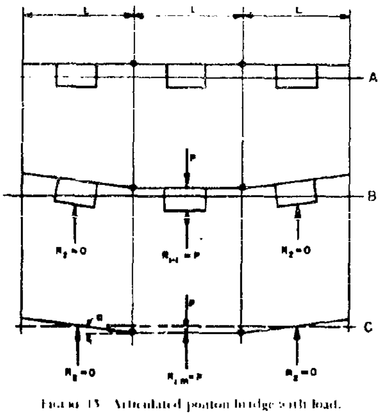


Figure 13. Articulated ponton bridge with load.

[e] Technical literature records many possible methods for the solution of equations. Obviously any other method desired by the computer might be substituted in Section 11.1.1.

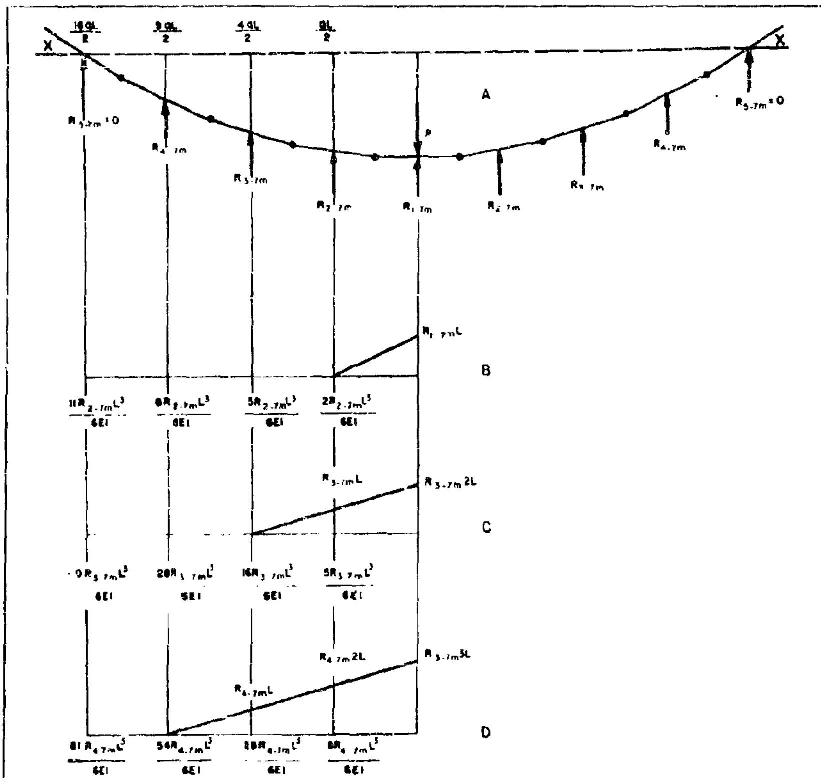


Figure 11. Seven rafts acting, maximum.

Added to the offsets due to articulation, there will be deflections due to load. For example, the two loads R_{2-7m} alone will cause a symmetrical moment curve (one half shown on line *B*), and, as may be shown by any method of computing beam deflections, will produce upward deflections above R_1, at the points of application of R_2, R_3, R_4, and R_5 = (0) of $2R_{2-7m}L^3/6EI$, $5R_{2-7m}L^3/6EI$, $8R_{2-7m}L^3/6EI$, and $11R_{2-7m}L^3/6EI$. Similarly, the moment curves and deflections produced by R_{3-7m} and R_{4-7m} are shown on lines *C* and *D*. It is understood that the offsets due to articulation and the three sets of deflections are acting simultaneously.

The difference in the reactions R_{1-7m} and R_{2-7m} will be *C* times the difference in the amounts by which the two pontons are submerged. That is, by again letting $CL^3/6EI$ equal *H*

$$R_{1-7m} - R_{2-7m} = C\left(\frac{aL}{2} + \frac{2R_{2-7m}L^3}{6EI} + \frac{5R_{3-7m}L^3}{6EI} + \frac{8R_{4-7m}L^3}{6EI}\right) = K + 2HR_{2-7m} + 5HR_{3-7m} + 8HR_{4-7m}.$$

In the same way

$$R_{1-7m} - R_{3-7m}$$

$$= C\left(\frac{4aL}{2} + \frac{5R_{2-7m}L^3}{6EI} + \frac{16R_{3-7m}L^3}{6EI} + \frac{28R_{4-7m}L^3}{6EI}\right)$$

$$= 4K + 5HR_{2-7m} + 16HR_{3-7m} + 28HR_{4-7m}.$$

$$R_{1-7m} - R_{4-7m}$$

$$= C\left(\frac{9aL}{2} + \frac{8R_{2-7m}L^3}{6EI} + \frac{28R_{3-7m}L^3}{6EI} + \frac{54R_{4-7m}L^3}{6EI}\right)$$

$$= 9K + 8HR_{2-7m} + 28HR_{3-7m} + 54HR_{4-7m}.$$

$$R_{1-7m} - 0$$

$$= C\left(\frac{16aL}{2} + \frac{11R_{2-7m}L^3}{6EI} + \frac{40R_{3-7m}L^3}{6EI} + \frac{81R_{4-7m}L^3}{6EI}\right)$$

$$= 16K + 11HR_{2-7m} + 40HR_{3-7m} + 81HR_{4-7m}.$$

Transposed, these four equations become

$$R_{1-7m} - (1 + 2H)R_{2-7m} - 5HR_{3-7m} - 8HR_{4-7m} = K,$$

$$R_{1-7m} - 5HR_{2-7m} - (1 + 16H)R_{3-7m} - 28HR_{4-7m} = 4K,$$

$$R_{1-7m} - 8HR_{2-7m} - 28HR_{3-7m} - (1 + 54H)R_{4-7m} = 9K,$$

$$R_{1-7m} - 11HR_{2-7m} - 40HR_{3-7m} - 81HR_{4-7m} = 16K.$$

Since H and K are constants with values fixed for any given bridge being investigated, it is apparent that four simultaneous equations with four unknowns (the values of the reactions) have been obtained. A solution yields the following values

$$R_{1-7m} = \frac{K(16 + 252H + 256H^2 + 41H^3)}{1 - 60H + 42H^2 - 3H^3},$$

$$R_{2-7m} = \frac{K(15 + 166H + 73H^2)}{1 - 60H + 42H^2 - 3H^3},$$

$$R_{3-7m} = \frac{K(12 + 29H - 30H^2)}{1 - 60H + 42H^2 - 3H^3},$$

$$R_{4-7m} = \frac{K(7 - 42H + 6H^2)}{1 - 60H + 42H^2 - 3H^3}.$$

The maximum load P_{7m} which seven rafts may carry without becoming the nine-raft case may be obtained from the equation

$$P_{7m} = R_{1-7m} + 2R_{2-7m} + 2R_{3-7m} + 2R_{4-7m}.$$

Substituting the values which have been obtained from the reactions,

$$P_{7m} = \frac{K(84 + 558H + 354H^2 + 41H^3)}{1 - 60H + 42H^2 - 3H^3}.$$

Seven Rafts Acting, Not Maximum

This case covers seven rafts supporting the load, but the load is not great enough to close the next joints. The first three equations for this case will be the same as the first three for the seven-raft-maximum case. The fourth equation is

$$R_{1-7} + 2R_{2-7} + 2R_{3-7} + 2R_{4-7} = P.$$

That is, the four equations which will permit determination of the reactions are

$$R_{1-7} - (1 + 2H)R_{2-7} - 5HR_{3-7} - 8HR_{4-7} = K,$$

$$R_{1-7} - 5HR_{2-7} - (1 + 16H)R_{3-7} - 28HR_{4-7} = 4K,$$

$$R_{1-7} - 8HR_{2-7} - 28HR_{3-7} - (1 + 54H)R_{4-7} = 9K,$$

$$R_{1-7} + 2R_{2-7} + 2R_{3-7} + 2R_{4-7} = P.$$

Solved, these yield the values

$$R_{1-7} = \frac{P(1 + 72H + 131H^2 + 26H^3) + K(28 - 26H + 2H^2)}{7 + 196H + 193H^2 + 26H^3},$$

$$R_{2-7} = \frac{P(1 + 57H + 46H^2) + K(21 + 16H - H^2)}{7 + 196H + 193H^2 + 26H^3},$$

$$R_{3-7} = \frac{P(1 + 23H - 18H^2) + K(65H + 11H^2)}{7 + 196H + 193H^2 + 26H^3},$$

$$R_{4-7} = \frac{P(1 - 18H + 3H^2) - K(35 + 68H + 11H^2)}{7 + 196H + 193H^2 + 26H^3}.$$

Five Rafts Acting, Maximum

Again use may be made of Figure 14, with the modification that $R_{4-5} = 0$, and line D consequently is meaningless. Proceeding as before,

$$R_{1-5m} - R_{2-5m}$$
$$= C\left(\frac{aL}{2} + \frac{2R_{2-5m}L^3}{6EI} + \frac{5R_{3-5m}L^3}{6EI}\right)$$
$$= K + 2HR_{2-5m} + 5HR_{3-5m}$$

$$R_{1-5m} - R_{3-5m}$$
$$= C\left(\frac{4aL}{2} + \frac{5R_{2-5m}L^3}{6EI} + \frac{16R_{3-5m}L^3}{6EI}\right)$$
$$= 4K + 5HR_{2-5m} + 16HR_{3-5m}$$

$$R_{1-5m} - 0 = C\left(\frac{aL}{2} + \frac{8R_{2-5m}L^3}{6EI} + \frac{28R_{3-5m}L^3}{6EI}\right)$$
$$= 9K + 8HR_{2-5m} + 28HR_{3-5m}$$

Transposing,

$$R_{1-5m} - (1 + 2H)R_{2-5m} - 5HR_{3-5m} = K,$$

$$R_{1-5m} - 5HR_{2-5m} - (1 + 16H)R_{3-5m} = 4K,$$

$$R_{1-5m} - 8HR_{2-5m} - 28HR_{3-5m} = 9K.$$

Solving,

$$R_{1-5m} = \frac{K(9 + 42H + 11H^2)}{1 - 18H + 3H^2},$$

$$R_{2-5m} = \frac{K(8 + 19H)}{1 - 18H + 3H^2},$$

$$R_{3-5m} = \frac{K(5 - 6H)}{1 - 18H + 3H^2}.$$

But $P_{5m} = R_{1-5m} + 2R_{2-5m} + 2R_{3-5m}$,

$$\text{i.e., } P_{5m} = \frac{K(35 + 68H + 11H^2)}{1 - 18H + 3H^2}.$$

This last value may be readily checked. In the seven raft case with load reduced until $R_{4-7} = 0$, giving the five raft maximum case, by setting R_{4-7} equal to zero in the case of seven rafts acting, not maximum, the above value is obtained.

Five Rafts Acting, Not Maximum

The first two equations are the same as for the five-raft-maximum case. The third equation is as given below:

$$R_{1-5} - (1 + 2H)R_{2-5} - 5HR_{3-5} = K$$

$$R_{1-5} - 5HR_{2-5} - (1 + 16H)R_{3-5} = 4K.$$

$$R_{1-5} + 2R_{2-5} + 2R_{3-5} = P.$$

When solved, these yield

$$R_{1-5} = \frac{P(1 + 18H + 7H^2) + K(10 - 2H)}{5 + 34H + 7H^2},$$

$$R_{2-5} = \frac{P(1 + 11H) + K(5 + 4H)}{5 + 34H + 7H^2},$$

$$R_{3-5} = \frac{P(1 - 3H) - K(10 + 3H)}{5 + 34H + 7H^2}.$$

Three Rafts Acting, Maximum

In the manner previously used, the following two equations are obtained:

$$R_{1-3m} - R_{2-3m} = C\left(\frac{aL}{2} + \frac{2R_{2-3m}L^3}{6EI}\right)$$
$$= K + 2HR_{2-3m}$$

$$R_{1-3m} - 0 = C\left(\frac{4aL}{2} + \frac{5R_{2-3m}L^3}{6EI}\right)$$
$$= 4K + 5HR_{2-3m}$$

Transposing,

$$R_{1-3m} - (1 + 2H)R_{2-3m} = K,$$

$$R_{1-3m} - 5HR_{2-3m} = 4K.$$

Solving,

$$R_{1-3m} = \frac{K(4 + 3H)}{1 - 3H},$$

$$R_{2-3m} = \frac{3K}{1 - 3H}.$$

But $P_{3m} = R_{1-3m} + 2R_{2-3m}$,

$$\text{that is, } P_{3m} = \frac{K(10 + 3H)}{1 - 3H}.$$

This value may be readily checked by setting $R_{3-5} = 0$.

EIGHT RAFTS ACTING, MAXIMUM

Figure 15 shows this case, with the various values having the same significance as in Figure 14. The displacements due to articulation and deflection are above the point of application of the load. The following equations may be written

$$R_{1-8m} - R_{2-8m} = C\left(\frac{1}{2}\frac{aL}{2} + \frac{5}{4}\frac{R_{1-8m}L^3}{6EI} + \frac{28}{4}\frac{R_{2-8m}L^3}{6EI} + \frac{47}{4}\frac{R_{3-8m}L^3}{6EI} + \frac{71}{4}\frac{R_{4-8m}L^3}{6EI}\right)$$

$$= 2K + \frac{5}{4}HR_{1-8m} + \frac{23}{4}HR_{2-8m} + \frac{47}{4}HR_{3-8m} + \frac{71}{4}HR_{4-8m}.$$

$$R_{1-8m} - R_{3-8m} = C\left(\frac{12}{2}\frac{aL}{2} + \frac{6}{4}\frac{R_{1-8m}L^3}{6EI} + \frac{50}{4}\frac{R_{2-8m}L^3}{6EI} + \frac{118}{4}\frac{R_{3-8m}L^3}{6EI} + \frac{190}{4}\frac{R_{4-8m}L^3}{6EI}\right)$$

$$= 6K + \frac{6}{4}HR_{1-8m} + \frac{50}{4}HR_{2-8m} + \frac{118}{4}HR_{3-8m} + \frac{190}{4}HR_{4-8m}.$$

$$R_{1-8m} - R_{4-8m} = C\left(\frac{21}{2}\frac{aL}{2} + \frac{9}{4}\frac{R_{1-8m}L^3}{6EI} + \frac{77}{4}\frac{R_{2-8m}L^3}{6EI} + \frac{193}{4}\frac{R_{3-8m}L^3}{6EI} + \frac{333}{4}\frac{R_{4-8m}L^3}{6EI}\right)$$

$$= 12K + \frac{9}{4}HR_{1-8m} + \frac{77}{4}HR_{2-8m} + \frac{193}{4}HR_{3-8m} + \frac{353}{4}HR_{4-8m}.$$

$$R_{1-8m} - 0 = C\left(\frac{40}{2}\frac{aL}{2} + \frac{12}{4}\frac{R_{1-8m}L^3}{6EI} + \frac{104}{4}\frac{R_{2-8m}L^3}{6EI} + \frac{268}{4}\frac{R_{3-8m}L^3}{6EI} + \frac{480}{4}\frac{R_{4-8m}L^3}{6EI}\right)$$

$$= 20K + \frac{12}{4}HR_{1-8m} + \frac{104}{4}HR_{2-8m} + \frac{268}{4}HR_{3-8m} + \frac{480}{4}HR_{4-8m}.$$

Transposing,

$$\left(1 - \frac{5}{4}H\right)R_{1-8m} + \left(-1 - \frac{23}{4}H\right)R_{2-8m} + \left(-\frac{47}{4}H\right)R_{3-8m} + \left(-\frac{71}{4}H\right)R_{4-8m} = 2K.$$

$$\left(1 - \frac{6}{4}H\right)R_{1-8m} + \left(-\frac{50}{4}H\right)R_{2-8m} + \left(-1 - \frac{118}{4}H\right)R_{3-8m} + \left(-\frac{190}{4}H\right)R_{4-8m} = 6K.$$

$$\left(1 - \frac{9}{4}H\right)R_{1-8m} + \left(-\frac{77}{4}H\right)R_{2-8m} + \left(-\frac{193}{4}H\right)R_{3-8m} + \left(-1 - \frac{333}{4}H\right)R_{4-8m} = 12K.$$

$$\left(1 - \frac{12}{4}H\right)R_{1-8m} + \left(-\frac{104}{4}H\right)R_{2-8m} + \left(-\frac{268}{4}H\right)R_{3-8m} + \left(-\frac{480}{4}H\right)R_{4-8m} = 20K.$$

Solved, these yield

$$R_{1-8m} = \frac{K\left(20 + 176H + 670H^2 + \frac{269}{2}H^3\right)}{1 - \frac{390}{4}H + \frac{483}{4}H^2 - \frac{81}{4}H^3 + \frac{3}{4}H^4},$$

$$R_{2-8m} = \frac{K\left(18 + 216H + \frac{191}{4}H^2 - \frac{57}{2}H^3\right)}{1 - \frac{390}{4}H + \frac{483}{4}H^2 - \frac{81}{4}H^3 + \frac{3}{4}H^4},$$

$$R_{3-8m} = \frac{K\left(14 + 13H - \frac{378}{4}H^2 + \frac{15}{2}H^3\right)}{1 - \frac{390}{4}H + \frac{483}{4}H^2 - \frac{81}{4}H^3 + \frac{3}{4}H^4},$$

$$R_{4-8m} = \frac{K\left(8 - 87H + 30H^2 - \frac{3}{2}H^3\right)}{1 - \frac{390}{4}H + \frac{483}{4}H^2 - \frac{81}{4}H^3 + \frac{3}{4}H^4}.$$

But

$$P_{8m} = 2R_{1-8m} + 2R_{2-8m} + 2R_{3-8m} + 2R_{4-8m}.$$

Substituting the values found above,

$$P_{8m} = \frac{K(120 + 1296H + 1308H^2 + 224H^3)}{1 - \frac{390}{4}H + \frac{483}{4}H^2 - \frac{81}{4}H^3 + \frac{3}{4}H^4}.$$

EIGHT RAFTS, NOT MAXIMUM

The first three equations are the same as those of the preceding case. These, together with the necessary fourth equation, are

$$\left(1-\frac{3}{4}H\right)R_{1-8}+\left(-1-\frac{23}{4}H\right)R_{2-8}+\left(-\frac{47}{4}H\right)R_{3-8}+\left(-\frac{71}{4}H\right)R_{4-8}=2K.$$

$$\left(1-\frac{6}{4}H\right)R_{1-8}+\left(-\frac{50}{4}H\right)R_{2-8}+\left(-1-\frac{118}{4}H\right)R_{3-8}+\left(-\frac{190}{4}H\right)R_{4-8}=6K.$$

$$\left(1-\frac{9}{4}H\right)R_{1-8}+\left(-\frac{77}{4}H\right)R_{2-8}+\left(-\frac{193}{4}H\right)R_{3-8}+\left(-1-\frac{133}{4}H\right)R_{4-8}=12K.$$

$$2R_{1-8}+2R_{2-8}+2R_{3-8}+2R_{4-8}=P.$$

Solving,

$$R_{1-8}=\frac{P\left(1+\frac{474}{4}H+\frac{1295}{4}H^2+\frac{341}{4}H^3\right)}{D}+\frac{K(40-48H+4H^2)}{D}.$$

$$R_{2-8}=\frac{P\left(1+\frac{330}{4}H+\frac{199}{4}H^2-18H^3\right)}{D}+\frac{K(21+96H-20H^2)}{D}.$$

$$R_{3-8}=\frac{P\left(1+\frac{110}{4}H-\frac{231}{4}H^2+\frac{18}{4}H^3\right)}{D}-\frac{K(8-160H-76H^2)}{D}.$$

$$R_{4-8}=\frac{P\left(1-\frac{138}{4}H+\frac{57}{4}H^2-\frac{3}{4}H^3\right)}{D}-\frac{K(56+208H+60H^2)}{D}.$$

where $D=8+388H+660H^2+112H^3$.

SIX RAFTS ACTING, MAXIMUM

In this case,

$$R_{1-6m}-R_{2-6m}=C\left(\frac{1}{2}\frac{aL}{2}+\frac{3}{4}\frac{R_{1-6m}L^3}{6EI}+\frac{23}{4}\frac{R_{2-6m}L^3}{6EI}+\frac{47}{4}\frac{R_{3-6m}L^3}{6EI}\right)$$

$$=2K+\frac{3}{4}H\,R_{1-6m}+\frac{23}{4}H\,R_{2-6m}+\frac{47}{4}H\,R_{3-6m}.$$

$$R_{1-6m}-R_{3-6m}=C\left(\frac{12}{2}\frac{aL}{2}+\frac{6}{4}\frac{R_{1-6m}L^3}{6EI}+\frac{50}{4}\frac{R_{2-6m}L^3}{6EI}+\frac{118}{4}\frac{R_{3-6m}L^3}{6EI}\right)$$

$$=6K+\frac{6}{4}HR_{1-6m}+\frac{50}{4}HR_{2-6m}+\frac{118}{4}HR_{3-6m}.$$

$$R_{1-6m}-0=C\left(\frac{24}{2}\frac{aL}{2}+\frac{9}{4}\frac{R_{1-6m}L^3}{6EI}+\frac{77}{4}\frac{R_{2-6m}L^3}{6EI}+\frac{193}{4}\frac{R_{3-6m}L^3}{6EI}\right)$$

$$=12K+\frac{9}{4}HR_{1-6m}+\frac{77}{4}HR_{2-6m}+\frac{193}{4}HR_{3-6m}.$$

That is,

$$\left(1-\frac{3}{4}H\right)R_{1-6m}+\left(-1-\frac{23}{4}H\right)R_{2-6m}+\left(-\frac{47}{4}H\right)R_{3-6m}=2K.$$

$$\left(1-\frac{6}{4}H\right)R_{1-6m}+\left(-\frac{50}{4}H\right)R_{2-6m}+\left(-1-\frac{118}{4}H\right)R_{3-6m}=6K.$$

$$\left(1-\frac{9}{4}H\right)R_{1-6m}+\left(-\frac{77}{4}H\right)R_{2-6m}+\left(-\frac{193}{4}H\right)R_{3-6m}=12K.$$

Solving,

$$R_{1-6m}=\frac{K(12+95H+36H^2)}{1-\frac{138}{4}H+\frac{57}{4}H^2-\frac{3}{4}H^3}.$$

$$R_{2-6m} = \frac{K\left(10 + 27\,H - \frac{15}{2}H^2\right)}{1 - \frac{138}{4}H + \frac{57}{4}H^2 - \frac{3}{4}H^3},$$

$$R_{3-6m} = \frac{K\left(6 - 18\,H + \frac{3}{4}H^2\right)}{1 - \frac{138}{4}H + \frac{57}{4}H^2 - \frac{3}{4}H^3}.$$

But $\quad P_{6m} = 2\,R_{1-6m} + 2\,R_{2-6m} + 2\,R_{3-6m}.$

$$\therefore \quad P_{6m} = \frac{K\,(56 + 208\,H + 60\,H^2)}{1 - \frac{138}{4}H + \frac{57}{4}H^2 - \frac{3}{4}H^3}.$$

It will be noticed that this same value is obtained when R_{4-6} is set equal to zero.

Six Rafts Acting, Not Maximum

Two of the equations for this case are the same as two for the six raft-maximum case. These, together with the third equation, are

$$\left(1 - \frac{3}{4}H\right)R_{1-6} + \left(-1 - \frac{23}{4}H\right)R_{2-6} + \left(-\frac{47}{4}H\right)R_{3-6} = 2K,$$

$$\left(1 - \frac{6}{4}H\right)R_{1-6} + \left(-\frac{50}{4}H\right)R_{2-6} + \left(-1 - \frac{118}{4}H\right)R_{3-6} = 6K,$$

$$2\,R_{1-6} + 2\,R_{2-6} + 2\,R_{3-6} = P.$$

When solved, these equations give the values

$$R_{1-6} = \frac{P\left(1 + \frac{141}{4}H + \frac{91}{4}H^2\right) + K\,(16 - 4\,H)}{6 + 88\,H + 38\,H^2}.$$

$$R_{2-6} = \frac{P\left(1 + 17\,H - \frac{9}{2}H^2\right) + K\,(4 + 20\,H)}{6 + 88\,H + 38\,H^2}.$$

$$R_{3-6} = \frac{P\left(1 - \frac{33}{4}H + \frac{3}{4}H^2\right) - K\,(20 + 16\,H)}{6 + 88\,H + 38\,H^2}$$

Four Rafts Acting, Maximum

Here

$$R_{1-4m} - R_{2-4m}$$

$$= C\left(\frac{4}{2}\frac{aL}{2} + \frac{3}{4}\frac{R_{1-4m}L^3}{6EI} + \frac{23}{4}\frac{R_{2-4m}L^3}{6EI}\right)$$

$$= 2K + \frac{3}{4}HR_{1-4m} + \frac{23}{4}HR_{2-4m}.$$

$$R_{1-4m} - 0$$

$$= C\left(\frac{12}{2}\frac{aL}{2} + \frac{6}{4}\frac{R_{1-4m}L^3}{6EI} + \frac{50}{4}\frac{R_{2-4m}L^3}{6EI}\right)$$

$$= 6\,K + \frac{6}{4}HR_{1-4m} + \frac{50}{4}HR_{2-4m}.$$

Transposing,

$$\left(1 - \frac{3}{4}H\right)R_{1-4m} + \left(-1 - \frac{23}{4}H\right)R_{2-4m} = 2K,$$

$$\left(1 - \frac{6}{4}H\right)R_{1-4m} + \left(-\frac{50}{4}H\right)R_{2-4m} = 6K.$$

Solving,

$$R_{1-4m} = \frac{K\left(6 + \frac{38}{4}H\right)}{1 - \frac{33}{4}H + \frac{3}{4}H^2},$$

$$R_{2-4m} = \frac{K\left(4 - \frac{6}{4}H\right)}{1 - \frac{33}{4}H + \frac{3}{4}H^2}.$$

From the equation

$$P_{4m} = 2\,R_{1-4m} + 2\,R_{2-4m},$$

there is obtained

$$P_{4m} = \frac{K\,(20 + 16\,H)}{1 - \frac{33}{4}H + \frac{3}{4}H^2},$$

the same value which comes from setting R_{3-4} equal to zero.

FOUR RAFTS ACTING, NOT MAXIMUM

The necessary equations for this case are

$$\left(1-\frac{3}{4}H\right)R_{1-4}+\left(-1-\frac{23}{4}\right)R_{2-4}=2K,$$

$$2R_{1-4}+2R_{2-4}=P.$$

These give the values

$$R_{1-4}=\frac{P\left(1+\frac{23}{4}H\right)+4K}{4+10H},$$

$$R_{2-4}=\frac{P\left(1-\frac{3}{4}H\right)-4K}{4+10H}.$$

TWO RAFTS ACTING, MAXIMUM

For this case the equation is

$$R_{1-2m}-0=C\left(\frac{4}{2}\frac{aL}{2}+\frac{3}{4}\frac{R_{1-2m}L}{6EI}\right)$$

$$=2K+\frac{3}{4}HR_{1-2m}.$$

This gives the value

$$R_{1-2m}=\frac{2K}{1-\frac{3}{4}H},$$

from which is obtained

$$P_{2m}=\frac{4K}{1-\frac{3}{4}H}.$$

TWO RAFTS ACTING, NOT MAXIMUM

In this case

$$R_{1-2}=\frac{P}{2}.$$

11.2.1 **Use of Equations**

When the make-up of the structure has been determined, values can be computed for K and H, and the values of P_{1m}, P_{2m}, P_{3m}, etc., can be computed. If, for example, the investigation is being conducted on an odd number of rafts and the load being considered lies between P_{5m} and P_{7m}, then the applicable case is *Seven Rafts Acting, Not Maximum*, and the equations for this case will give the values of the reactions and permit determination of the shear and moment curves.

11.2.2 **Loads Different From a Single Concentrated Load**

Each of the foregoing derivations has been made for a single concentrated load placed at the middle of the structure. Provided an actual tank, truck, or other load is not spread over too great a length, fair accuracy will be obtained by assuming that the *reactions* will be the same as for a single concentrated load of the same magnitude. The actual distribution of loads, however, will be used in drawing shear and moment curves. It is felt that the error due to this assumption will be no greater than those errors arising from variations in articulation due to shop inaccuracies and to disregard of the facts that the pontons do not have the shape of a box, and that submergence and reaction are not directly proportional.

11.2.3 **Identity of Methods**

The methods used with articulated bridges may be applied to continuous, unarticulated structures if K is set equal to zero. Thus, for continuous structures, the methods summarized at the end of this section and those at the end of the section on continuous structures should give identical results. This may be illustrated by an investigation of the five-ponton structure of Figure 16. Two equations may be written (for $f=1$, and $f=2$), since by symmetry there are only two unknown interior ponton reactions.

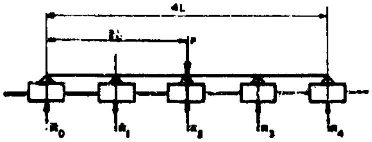


FIGURE 16. Continuous five ponton structure and load.

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For $f = 1$,

$$R_1\left(4 - 1 - 1 + \frac{2 \cdot 1 \cdot 1}{4}\right)$$
$$+ R_2\left(4 - 2 - 1 + \frac{2 \cdot 1 \cdot 2}{4}\right)$$
$$+ R_3\left(4 - 3 - 1 + \frac{2 \cdot 1 \cdot 3}{4}\right)$$
$$+ R_1 H\,(2 \cdot 1 \cdot 9) + 4R_1$$
$$+ R_2 H\,[1 \cdot 2(2 \cdot 4 \cdot 2 - 4 - 1)]$$
$$+ R_3 H\,[1 \cdot 1\,(2 \cdot 4 \cdot 3 - 9 - 1)]$$
$$= P\left[4 - 2 - 1 + \frac{2 \cdot 1 \cdot 2}{4}\right]$$
$$+ PH\,[2 \cdot 1(2 \cdot 4 \cdot 2 - 4 - 1)].$$

Since $R_3 = R_1$, this may be rewritten

$$8R_1 + 32HR_1 + 2R_2 + 22HR_2 = 2P + 22HP.$$

Similarly, for $f = 2$,

$$R_1\left[4 - 1 - 2 + \frac{2 \cdot 2 \cdot 1}{4}\right]$$
$$+ R_2\left[4 - 2 - 2 + \frac{2 \cdot 2 \cdot 2}{4}\right]$$
$$+ R_3\left[4 - 3 - 2 + \frac{2 \cdot 2 \cdot 3}{4}\right]$$
$$+ R_1 H\,[1 \cdot 2(2 \cdot 4 \cdot 2 - 1 - 4)]$$
$$+ R_2 H\,[2 \cdot 4 \cdot 4] + 4R_2$$
$$+ R_3 H\,[2 \cdot 1(2 \cdot 4 \cdot 3 - 9 - 4)]$$
$$= P\left[4 - 2 - 2 + \frac{2 \cdot 2 \cdot 2}{4}\right]$$
$$+ PH[2 \cdot 4 \cdot 4].$$

Or

$$4R_1 + 44HR_1 + 6R_2 + 32HR_2 = 2P + 32HP.$$

Therefore, dividing all terms by 2,

$$R_1 = \frac{P\begin{vmatrix}1 + 11H & 1 + 11H \\ 1 + 16H & 3 + 16H\end{vmatrix}}{\begin{vmatrix}4 + 16H & 1 + 11H \\ 2 + 22H & 3 + 16H\end{vmatrix}}$$

$$= \frac{P(3 + 49H + 176H^2 - 1 - 27H - 176H^2)}{12 + 112H + 256H^2 - 2 - 44H - 242H^2}$$

$$= \frac{P(2 + 22H)}{10 + 68H + 14H^2} = \frac{P(1 + 11H)}{5 + 34H + 7H^2}$$

$$R_2 = \frac{P\begin{vmatrix}4 + 16H & 1 + 11H \\ 2 + 22H & 1 + 16H\end{vmatrix}}{10 + 68H + 14H^2}$$

$$= \frac{P(4 + 80H + 256H^2 - 2 - 44H - 242H^2)}{10 + 68H + 14H^2}$$

$$= \frac{P(2 + 36H + 14H^2)}{10 + 68H + 14H^2} = \frac{P(1 + 18H + 7H^2)}{5 + 34H + 7H^2}.$$

The value of R_0 ($= R_4$) may be obtained from the equation $\Sigma V = 0$. That is,

$$2R_0 + 2R_1 + R_2 - P = 0,$$

$$R_0 = \tfrac{1}{2}(P - 2R_1 - R_2).$$

$$= \tfrac{1}{2}\left[P - \frac{2P(1 + 11H) + P(1 + 18H + 7H^2)}{5 + 34H + 7H^2}\right]$$

$$= \frac{P}{2}\;\frac{5 + 34H + 7H^2 - 2 - 22H - 1 - 18H - 7H^2}{5 + 34H + 7H^2}$$

$$= \frac{P}{2}\;\frac{2 - 6H}{5 + 34H + 7H^2} = \frac{P(1 - 3H)}{5 + 34H + 7H^2}.$$

The following comparison is found between the notations of the summaries for the unarticulated and the articulated bridge reactions:

Unarticulated		Articulated
R_{1-3}	=	R_2
R_{2-3}	=	R_1
R_{3-3}	=	R_0

The values computed are the same for the case in which $K = 0$. The methods of analyzing articulated bridges, however, will give increased speed for cases of symmetrical loading in continuous, unarticulated bridges provided that the actual load does not have too great a distribution.

Reactions of Ponton Bridges
(with articulations)

METHOD OF USE

[illegible]

Notation

$$N = \frac{CL^3}{EI}$$

$$\text{and } K = \frac{C\alpha L}{2}$$

where E = [illegible]
I = [illegible]
α = [illegible]
L = [illegible]
C = [illegible]

[illegible]

[redacted]

Reactions of Ponton Bridges

(with articulations)

METHOD OF USE

[illegible]

Notation

$$M = \frac{CL^3}{EI}$$

and $K = \frac{C\alpha L}{2}$

where
- E = Modulus of elasticity of balk.
- I = Moment of inertia of balk.
- α = Angle of articulation (radians) between rafts.
- L = Length of one raft.
- C = Raft displacement per unit of depth.

[illegible]

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Chapter 12

BRIDGE, PONTON, AND FERRY DESIGNS

Summary

Designs for a variety of structures intended for military use—bridges, pontons, and ferries—were prepared at the request of the Engineer Board of the U. S. Army Corps of Engineers.

Among the structures designed are a 20-ton articulated bridge, a portable ponton bridge and ferry for 30-ton tanks, a structure which can be used as a ponton bridge or as a trestle or overpass for 60-ton tanks, a bridge constructed largely of steel pipe, a 200-foot portable bridge to carry a 30-ton tank, temporary highway trestles, a ponton ferry to support a 90-ton tank, tank-ferrying barges, and an amphibious paddle-wheel towboat. Other bridges already being used or contemplated by the Army were also studied, and in some cases these were redesigned for additional applications. Similar designs were made for ramps for some of these bridges.

In order to provide facilities for landing tanks, a landing pier was designed to handle a 30-ton tank at sites where tides up to 20 feet may exist.

With the expected need for repairing or replacing enemy-damaged quays in occupied territory, a series of alternate designs was developed for foundations and floor systems.

12.1 ARTICULATED BRIDGE FOR 20-TON LOADS

To meet the need for an articulated bridge on rubber floats to carry division loads up to 20 tons, designs were prepared for a structure to make use of wooden floor chess and rubber floats already stocked by the Army.[a]

The design shown in Figure 1 contemplates the use of five parallel, welded-steel balk as main carrying members, each approximately $5\frac{1}{4}$ inches wide, 16 inches deep, 15 feet long, and weighing 330 pounds. The details are so arranged that the balk are alike end for end and top for bottom and cannot be assembled in a wrong position.

Because the loads to be carried and their positions on the roadway are not definite, and because the chess to be used are rather thin, there is uncertainty regarding the division of loads among the five balk in any span. As far as moment is concerned, this is not so serious, since four balk have sufficient strength to carry the moments if these are equally divided. In the case of shear, however, particularly in the simple spans at the ends of a structure, this may cause

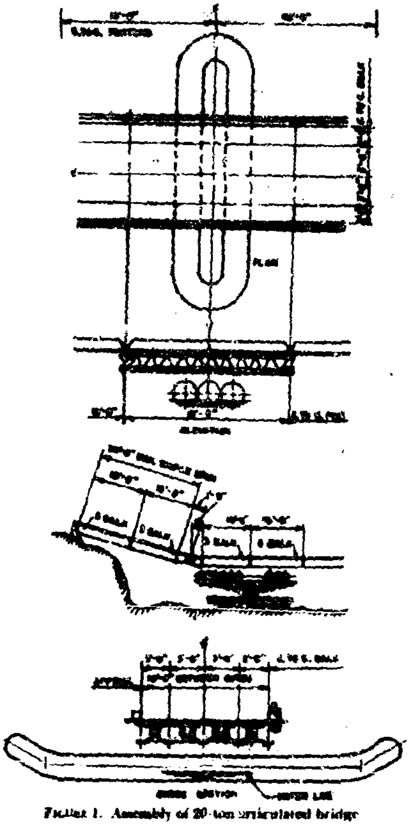

Figure 1. Assembly of 20-ton articulated bridge

[a] This investigation was conducted by the Drexel Institute of Technology, Philadelphia, Pa., under OSRD contract OEMsr-41, and by Carson & Carson, Philadelphia, Pa., under contract NDCrc-41 and OSRD contract OEMsr-216.

trouble and a slight increase might be required in the size of one or two diagonals at each end of each balk.[15]

115 50-TON TANK PONTON BRIDGE AND FERRY

Designs have been prepared for a portable ponton bridge and ferry, each suitable for carrying loads up to and including 50-ton tanks. The equipment has been planned to give maximum ruggedness, simplicity, interchangeability, and mobility to meet military field requirements.[b]

The general structure of the ponton bridge set up for a 210 foot crossing is indicated in Figure 2. It consists of ramp sections supported on special spread bearing shoes at their shore ends and double pontons at their river ends for both ends of the bridge. Between the double pontons is a series of spans supported on single pontons. The bridge deck consists of all-welded panels. The pontons, also all-welded, have rectangular sections throughout, and each is divided into four watertight compartments, stiffened with lattice frames, and equipped with manholes to permit ready access to the interior.

All the units for this 210-foot bridge would weigh 161,200 pounds or 765 pounds per linear foot of bridge, and could be transported together with a crane and necessary personnel on ten 12-ton articulated trailer trucks.

By adding auxiliary molded ends, two bridge pontons (Figure 5) and one section of bridge deck can be combined to give a ferry 20x36x3 feet deep (Figure 4). Fully loaded, this ferry has a displacement of 28½ inches, leaving a freeboard height of 7½ inches. The ferry itself has a weight of 35,200 pounds.

The transportation requirements would fit in very well with the requirements of the ponton bridge, for two additional trucks would provide transportation for the formed ends of two sections and for loading aprons required for two banks. To provide a complete ferrying unit composed of two ferries and two loading aprons, together with a truck crane, hand tools, and necessary personnel, seven 12-ton trailer trucks would be needed.

[b] This investigation was conducted by the American Bridge Company, Pittsburgh, Pa.

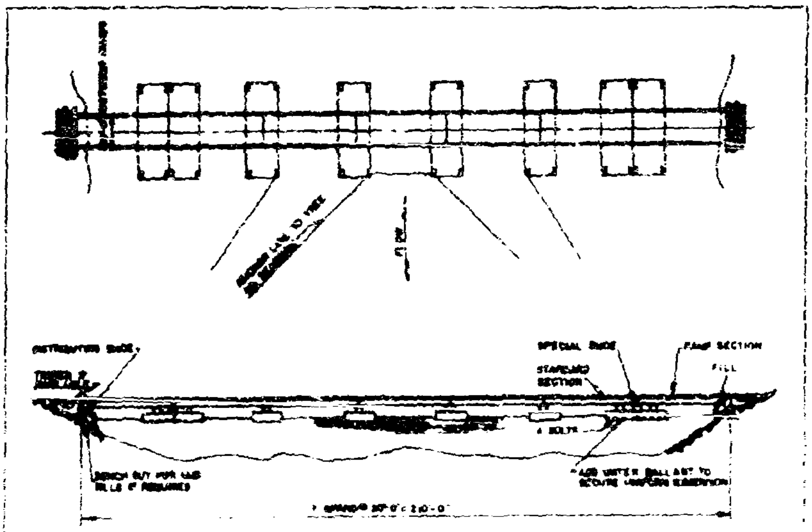

FIGURE 2. Assembly of 50 ton bridge

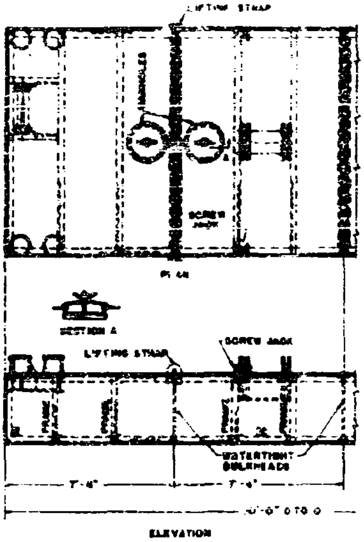

Figure 3. Ponton for 50-ton tank bridge

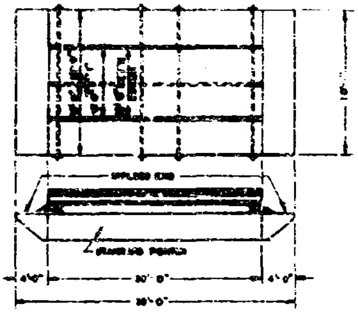

Figure 4. Ponton modified with molded ends to serve as 50-ton tank ferry.

It is believed that expansion of the basic principles developed in this study would lead to satisfactory designs for ponton bridges and ferries to accommodate 50-ton tanks.[9]

12.3 60-TON TANK TRESTLE AND PONTON BRIDGE

Designs have been made for a trestle structure that can support a 60-ton tank and can serve, with some modifications, as parts of a ponton bridge.[4]

As a trestle (Figure 5), the proposed structure consists of bents (two columns and a transom) spaced about 25 feet apart. By splicing the columns, the floor may be placed about 40 feet above the bottom of the column grillage. The bents support longitudinal, welded, open-webbed balk that carry the floor beams and an open-grid floor. Six balk are required in each span to support a 60-ton tank, four to carry a 30-ton tank. The same structure may be used as an overpass (Figure 6) and presumably as a dock or as a trestle for light railroad loads.

The same grid floor, floor beams, and balk will serve as a ponton bridge, with the balk resting on 25-ton pontons (Figure 7). Special connections are planned to reduce the bending moment in the balk and to take advantage of the ponton flotation under and near the load. For use as a bridge, the structure would be assembled into 25-foot rafts, with three pontons per raft for 60-ton tanks and two for 30-ton loads.[11]

Reliance for longitudinal stability is placed on

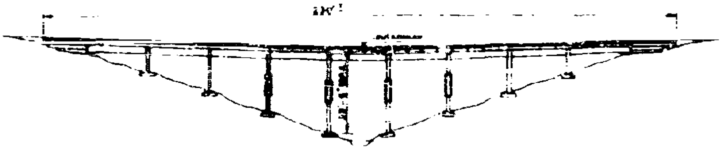

Figure 5. Assembly of 60-ton tank trestle

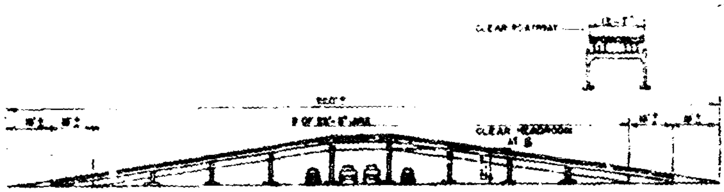

Figure 6. Assembly of 80-ton tank overpass

pare on a detail involving the use of set screws. Laboratory tests showed that such screws have sufficient holding power to take a load of 5,600 pounds without slipping.[11]

Since the attention of the Engineer Board was taken by other bridges, studies were not continued beyond the preliminary design stage.[12]

124 TUBE BRIDGE

A bridge design taking advantage of the load-resisting properties of steel tubes has been prepared for truck, tank, and railroad loads.[a] For tanks, if only one were allowed on the bridge at a time, the structure would permit a 60-ton load on a 150-foot span, a 50-ton load on a 180-foot span, and a 20-ton load on a 210-foot span. Considering its capacity, the bridge is relatively light in weight, its heaviest standard member weighing about 1,850 pounds, and all its members may be readily nested and transported.

The features of the design are shown in Figure 8. For use as a highway bridge, steel guardrails are furnished and the space between top chords is filled in with an open-grid steel floor which will be flush top with the chord. Four floor sections, each weighing about 220 pounds, are used to fill in the 5-foot panel between two floor beams. The structure may be used as a railway bridge if the guardrail and open-grid floor are replaced with 8x8 inch ties, 12 feet 6 inches long, placed 14 inches center to center on the top chords.

125 THE INGLIS BRIDGE

The Inglis bridge,[c] with trusses composed of pin-connected tubular members, was examined, and a study made of its capacity based upon conservative allowable unit stresses and its use as a double-story bridge.[d]

The greatest element of weakness in the structure appears to be in the lack of top-chord bracing in the single-story bridge. As built, there seems to be no justification for the assumption that the unsupported length of the top-chord members is one panel length or 12 feet. The loadings given in the design of the bridge have a factor of safety of 1.07 and cannot be regarded as allowable for prolonged service. For all cases except the single-story, single-tube one, the structure will be materially weakened and probably unsafe unless all of the compression collars are screwed out to their full travel.[2]

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[c] A portable bridge designed by Professor C. E. Inglis, built by the Royal Engineers.

[d] This investigation was conducted by the Drexel Institute of Technology, Philadelphia, Pa., under OSRD contract OEMsr-43.

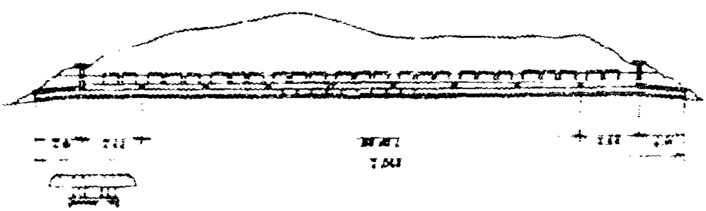

Figure 7. Assembly of 90-ton tank ponton bridge

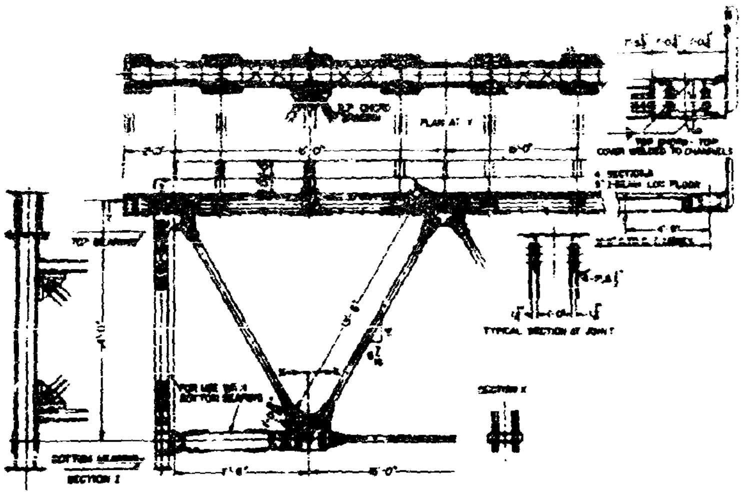

Figure 9. Details of tube bridge construction

12.6 200-FOOT PORTABLE BRIDGE

A 200-foot portable bridge to carry the medium tank, with a weight of about $27\frac{1}{2}$ to 30 tons, has been designed with open-type floor, floor beams, chords, end posts, and main gusset plates to be made of alloy steel, and the other web members to be made of ordinary bridge steel.

The construction is illustrated in Figure 9. In order to settle the relative erection advantages of pin connections and bolts, alternate designs were prepared, one showing bolted and the other pin-connected construction. Once it has been determined which type is preferable a light traveller may be designed to run on the curb channels of the floor and to serve for the erection of the structure.

The plans as shown here have been made with the presumption of using cantilever erection. In the case of either cantilever or swing erection the size of the chord members would be determined by the erection stresses. It is believed that if this design be completed temporary strengthening of a few of the chord members at the center of the structure for these erection stresses would permit extending the bridge for spans up to 200 or 240 feet.

12.7 BETHLEHEM STEEL COMPANY PORTABLE BRIDGES

Designs for two portable bridges of 200-foot maximum clear span were examined to determine their general suitability and safety.[4] Each bridge as planned by the Bethlehem Steel Company would be erected as a cantilever from similar parts that serve as an anchor arm counterweighted for erection. In each case it was intended to use the anchor arm and the cantilever, when completed, as a continuous span.

The first of these, Bethlehem Scheme E, is a design for a bridge made up of box sections 26 feet long, 5 feet wide, and 11 feet deep. The intermediate sections weigh 12,300 pounds each. Two trusses composed of these box sections are spaced 9 feet center to center and carry on their upper chords a roadway of 18 feet clear width. An erection method is proposed to allow the placing of a 102-foot anchor arm and a 200-foot cantilever arm complete with floor in 30 minutes. The bridge was designed to support a 30-ton truck with a 16-ton trailer in each of two lanes. It contemplates the use of an alloy steel with a [illegible]

Similar box sections are planned for Bethlehem Scheme F, but in this plan floor sections are permanently attached to floor beams at the top-chord level so that the longitudinal members of the floor will assist the chords in carrying compression. Since only one lane of tanks or heavy trucks may be supported, the total weight of the structure will be considerably less than that of Scheme E.

It was determined that both schemes are, or can readily be made, satisfactory from a design standpoint, and once in place will safely carry their loads.[9]

12.4 SOLID-FLOOR TREADWAY BRIDGE

Several years ago, the U. S. Army developed a bridge that utilized treadways on rubber floats. As main members, the superstructure has four 15-inch channels, connected to furnish the two treadways as

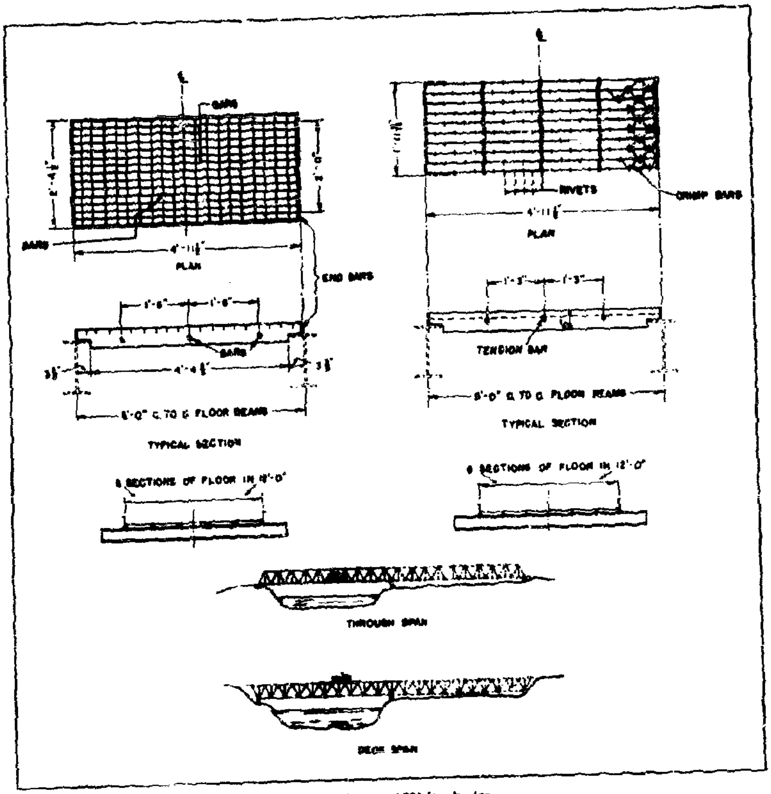

Figure 9 Design of 200-foot bridge.

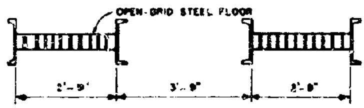

FIGURE 10. Cross section of old treadway bridge.

shown in Figure 10. In order to accommodate loads with a width of contact of 120 inches, however, it became necessary to redesign the structure.[8]

Immediate analysis showed that if the same general arrangement were retained, the new design would involve widening the treads but retaining the distance between inner channels to permit passage of the ¾-ton truck. The presence of these inner curbs is undesirable, for certain vehicles tend to ride them. Furthermore, it is generally appreciated that traffic slows up when approaching treads, and that this may result in serious congestion particularly under blackout conditions. Consequently, a new design was prepared as shown in Figure 11, with a solid floor and a width of 11 feet 9 inches, in contrast to 9 feet 5 inches for the old bridge.[14]

It became necessary later to develop a ramp for this new bridge which would permit traffic to enter and leave it under considerable change in water level, such as would exist on a tidal stream. The ramp designed for this purpose is shown in Figure

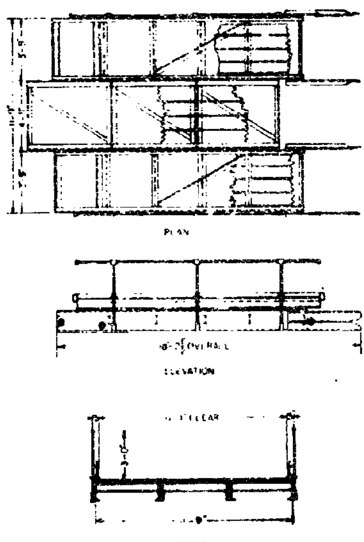

FIGURE 11. Design of solid floor treadway bridge.

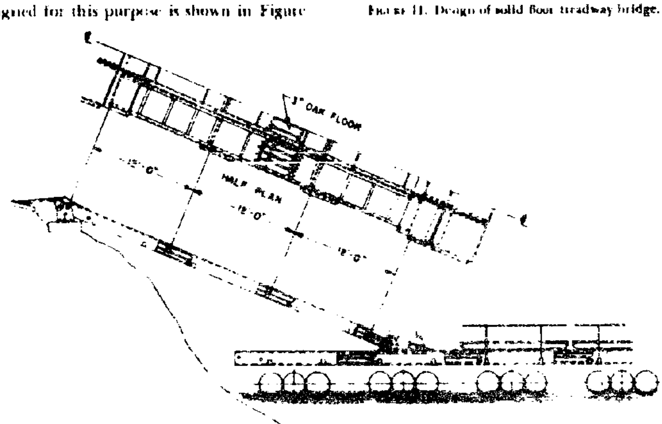

FIGURE 12. Ramp for solid floor bridge.

12. Under controlled traffic conditions, that is, without impact, a three-section ramp 38 feet 6 inches long will support a 34-ton tank, and a two-section ramp 26 feet 6 inches long will hold a 55-ton tank.[20]

12.9 RAMP FOR SPARKMAN AND STEPHENS BRIDGE

At the request of the Engineer Board, a design was made for a landing ramp to be used with the Army bridge devised by Sparkman and Stephens.[9] The design, as shown in Figure 13, calls for complete units 33 feet long with a clear roadway of 12 feet 5¾ inches.[41]

12.10 PORTABLE RAILWAY BRIDGE

In order to determine the possibility of using the U. S. Army H-20 portable steel highway bridge as a railway bridge, allowable Cooper loads and deflections were computed for span lengths of 37½ to 100 feet.[5] Two floor systems were considered, one (A) using at the panel points of the trusses a number of 8x10-inch timbers, 6 feet 3 inches center to center, and stringers of the same size over the trusses in order to avoid bending stresses in the truss chords, and another (B) in which the ties rest directly on the top chords of the trusses.

For plan A, the allowable Cooper load ranges from E-34 to E-7 for span lengths of 37½ to 100 feet, providing two trusses are used, and from E-51 to E-11, providing three trusses are used.

For plan B, the allowable load ranges from E-32 to E-6 for span lengths of 37½ to 100 feet with two trusses, and from E-48 to E-10 with three trusses.[10]

12.11 TEMPORARY HIGHWAY TRESTLES

Three designs for temporary highway trestles have been prepared to provide structures which can be erected easily and quickly in the field. Wood piles and caps are used in one case, steel H-section piles and steel channel caps in another, and steel pipe piles and steel channel caps in a third. The superstructure above the caps, including stringers and roadway, is the same for all three designs. The general features of the plans are illustrated in Figures 14, 15, and 16.

The pipe pile construction appears to lend itself more readily to the requirements because of the simplicity of field connections. This design provides for pipe plug application of the cap assembly and pin connection of the stringers to the caps. Bracing details are also simplified, and this type of trestle can probably be erected more rapidly than can either of the other two.

A unit similar in construction to the Austin Western "Badger" crane rigged as a pile driver, with or without hanging leads, should be able to handle the piling. Necessary modifications include the selection of a power unit of sufficient capacity to handle the crane, and the addition of a 315-cubic-foot air compressor.

While soil conditions at the site will determine the speed, a time schedule of 40 minutes for driving one bent and one panel appears reasonable. This is based

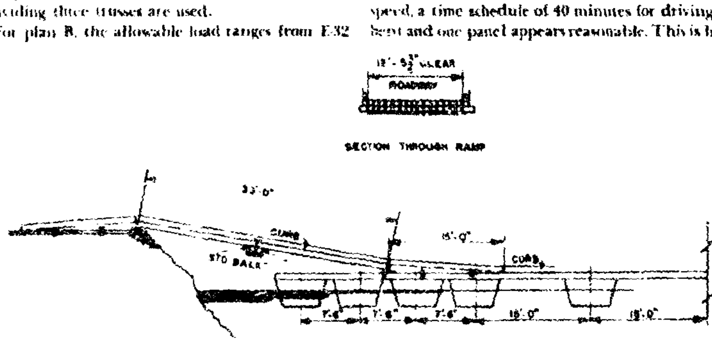

FIGURE 13. Ramp for Sparkman & Stephens Army trestle bridge showing experimental approach.

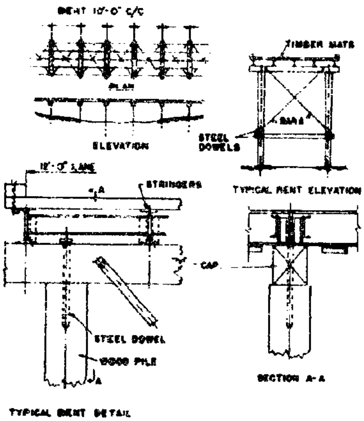

FIGURE 14. Design of temporary highway trestle wood pile construction.

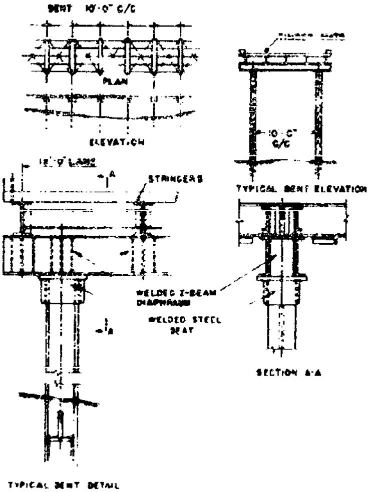

FIGURE 15. Design of temporary highway trestle steel H pile construction.

on complete preliminary preparation and on assurances that the cap assembly and panel deck and the stringer assembly are all available within reach of the power-driven unit.[3]

12.12 90-TON TANK PONTON FERRY

Plans have been made for a heavy ponton ferry, capable of carrying a 90-ton tank or equivalent loads of fuel, water, personnel, or other military supplies.[e] As shown in Figure 17, the ferry consists of four units, each 40 feet long, 10 feet wide, and 4 feet high, constructed of electrically welded carbon or alloy steel with watertight compartments. Construction of one unit is illustrated in Figure 18.

The units can be carried on trucks, trailers, or

[e] This investigation was conducted by T. R. Tarn, Pittsburgh, Pa., under OSRD contract OEMsr-158.

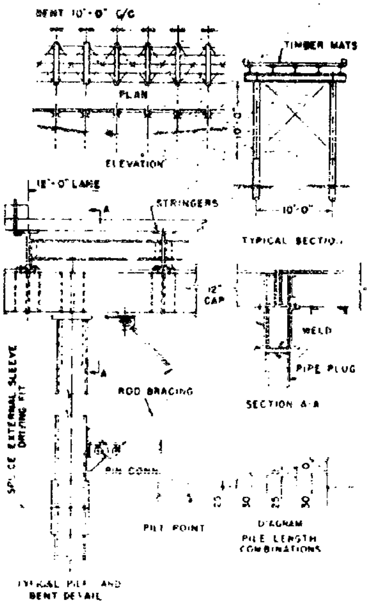

FIGURE 16. Design of temporary highway trestle steel pipe construction.

freight cars, and can be assembled in 20 minutes or less. They can be used as separate units, in groups, or as a continuous articulated floating ponton bridge.

A separate, self-contained towboat is recommended as the most desirable means of propulsion, although either demountable or permanent propelling equipment can be installed on the units. Designs for a suitable towboat and a method of transporting it on land are given in Figure 19.

Equipment to transport and place in service one four-unit ferry consists of eight transport trucks and four Caterpillar-type tractors. In addition, eight transport trucks would be needed to carry the two towboats, two tractors for the towboats, and two tractors for launching material.[e]

In order to simplify launching and assembling operations, plans were made later for movable confined launching cradles that carry a ponton unit on steel runners, and in turn are carried on rollers installed within the side frame portions of the trailer chassis. These make it possible to launch the pontons directly into the water. Each transport unit—a tractor and its trailer—is therefore completely equipped as a self-supporting and self-contained unit to serve as a transport and launching medium for one ponton unit.[7]

12.13 DUKWS AS PONTONS

In another section of this volume, a report is presented on the use of the amphibious DUKW as a ponton ferry and its possible use in a ponton bridge.[f]

12.14 TANK-FERRYING BARGES

In order to ferry tanks and similar loads weighing up to 90 tons, small barge units were designed in May 1941 as shown in Figure 20.[g] Each barge would be 14 feet 5 inches long and 7 feet 6 inches wide, constructed of welded steel, and weighing about 2,500 pounds. With 16 barges carrying a 90-ton tank, displacement to a 2-foot 5-inch water line in fresh water would be about 13,250 pounds, leaving a freeboard of 2 feet 7 inches. The barges could be nested for transportation.

[f] See Chapter 3.

[g] This investigation was conducted by Sparkman & Stephens, Inc., New York, N. Y., under OSRD contract OEMsr-86.

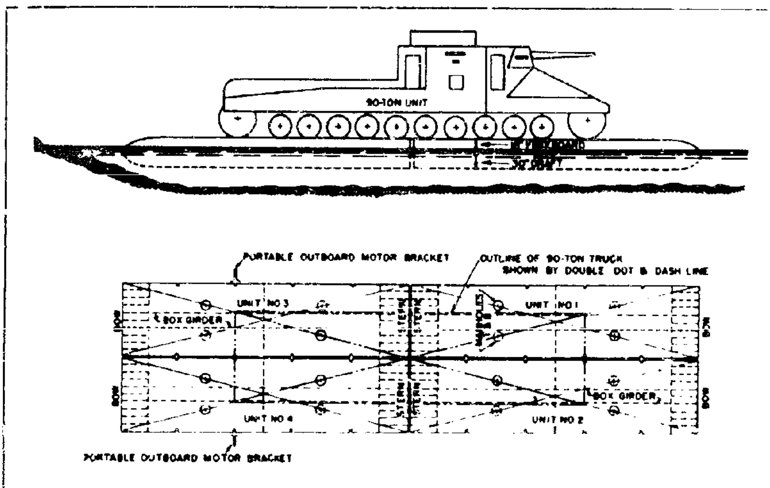

Figure 17. Assembly of 90-ton tank ponton ferry.

If the barges could be built of plywood skin on a steel frame, the weight could probably be reduced to about 1,500 pounds.

Pin connections were designed primarily for ease in assembling the units, and to provide for both tensile and compression loads in a fore-and-aft direction. Transverse loads would be handled by separately applied steel girders.

Many of the features of this design later found application in the so-called Rhino ferry used by the Army, and the nesting feature is used in many American and foreign ponton bridges.

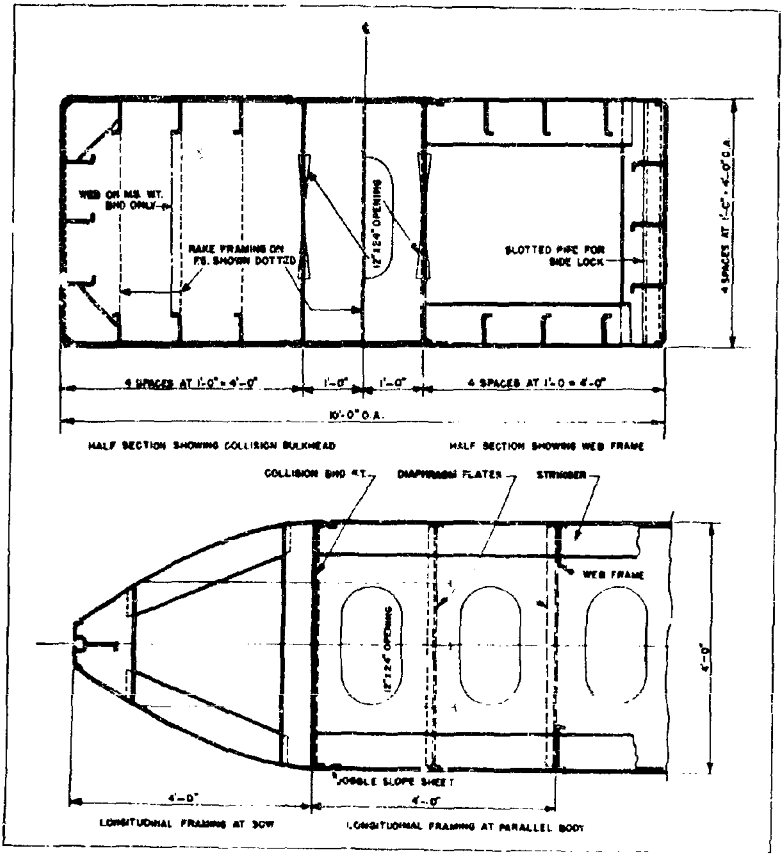

FIGURE 18. Plan and side elevation of ponton for [illegible]-ton tank ponton ferry.

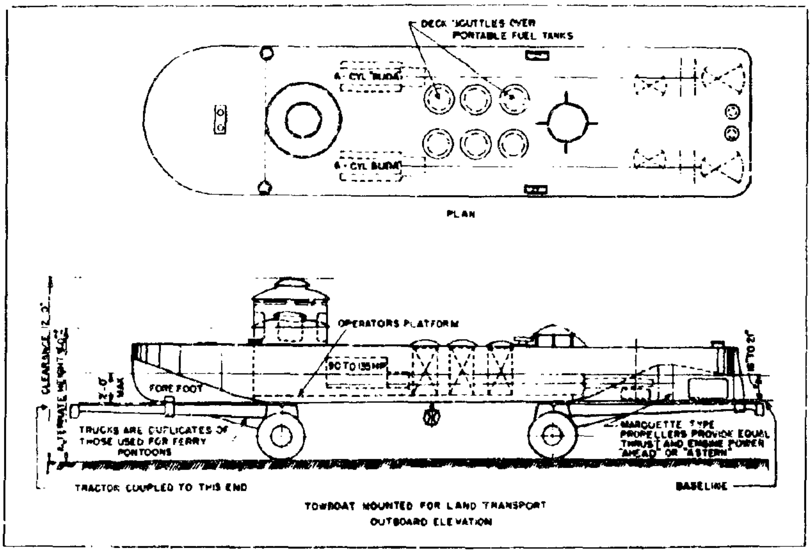

FIGURE 19. Towboat for 90 ton tank ponton ferry.

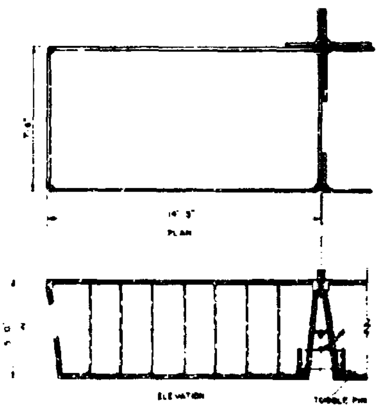

FIGURE 20. Plan and side elevation view of erectible tank ferrying barges.

The basic features of the A-frame are shown in Figure 21. This structure would be built of welded steel pipe, with each section about 22 feet long and weighing less than 2,500 pounds. The members would be arranged in the form of a truss, with additional cross members to provide extra local support to the longitudinal members where they are carrying a runway. The A-frame would provide a means of lifting and suspending a 90-ton tank after it had been launched in shallow water. If an I-shaped center link were substituted for the section carrying the chain hoists, a flat bridge-type structure could be made for suspension between barge units to give a loading platform. With suitable linkages between the ends of such platform sections, these could be formed into a ponton bridge.

Arrangements proposed to meet various ferrying and loading conditions are indicated in the diagrams in Figure 22.

Two towing vessels were designed for use with these barges, one an amphibious paddle-wheel tow

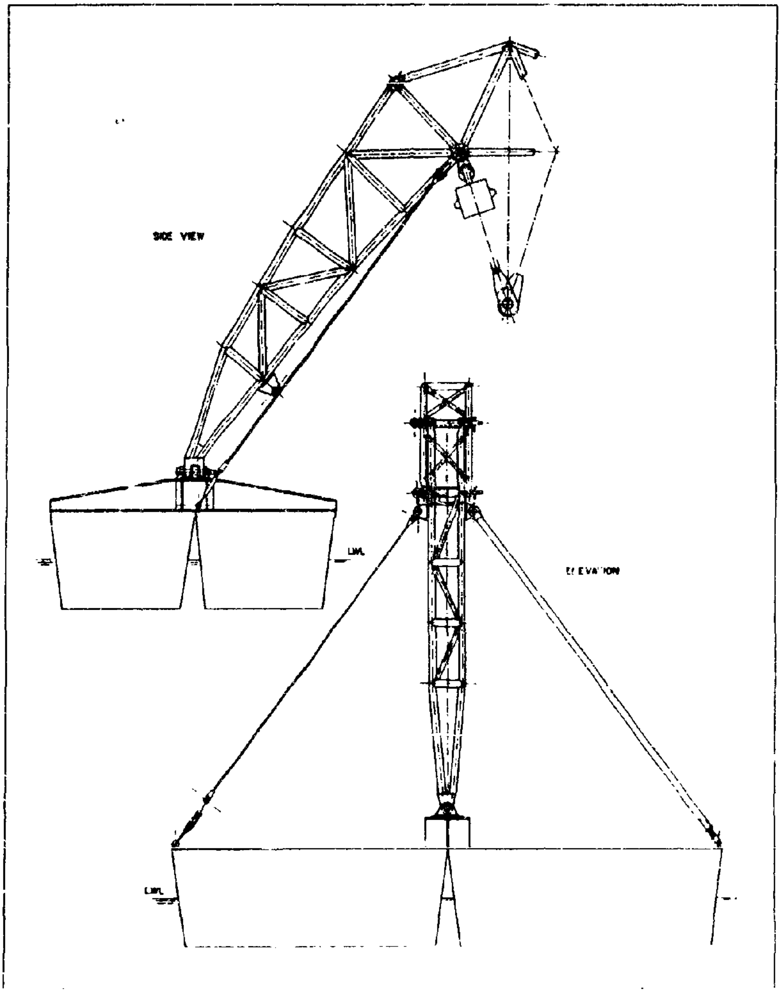

Figure 21. A-frame for loading tank-ferrying barges

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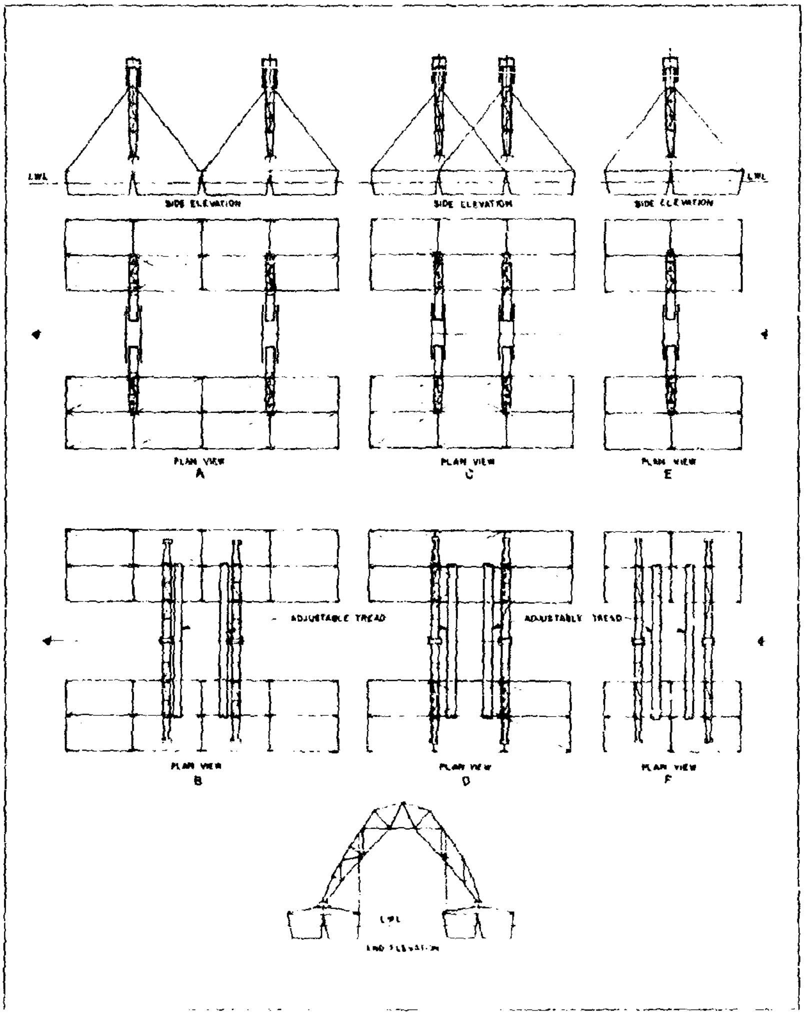

FIGURE 22. Loading arrangements for tank ferrying barges.

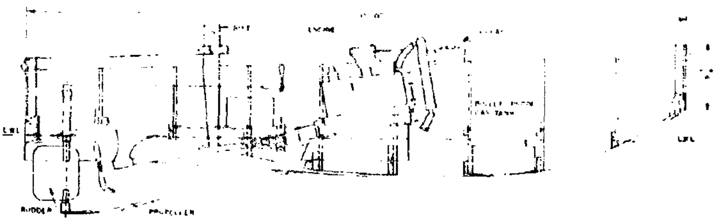

FIGURE 23. Tunnel stern towboat.

boat[a] and the other a tunnel stern towboat. The latter, shown in Figure 23, would be constructed of phenolic resin plywood on oak frames and powered by a Ford V 8 automobile gasoline engine fitted with a marine clutch, a reverse gear, a reduction gear, and a thrust bearing. An automobile-type radiator would provide fresh water cooling. With a screw propeller housed in a stern tunnel, this boat would be able to work efficiently in shallow water. Its over-all length would be 15 feet, its beam 6 feet 6 inches, its depth 3 feet 6 inches, its weight about 2,100 pounds, and its speed about 15 knots.

Although it is believed that a towboat generally similar to one of those mentioned above would provide the most flexible single means of propulsion under varying conditions, other possibilities may be considered. Outboard motors, mounted on brackets on the barges or on small wooden boats designed to nest in the barges, would be satisfactory for small loads but probably not for tanks weighing more than about 30 tons. An endless cable or ski tow arrangement would presumably provide the most efficient use of power and could be considered in more detail, but would need equipment on both shores of the water to be crossed. Paddle or propeller drives using power take-off from the tanks themselves could be developed, as could removable fins or paddles on the tank treads.

The carrying method outlined here appears to be particularly practical and flexible. It would have great value in ferrying to or from a gradually shoaling river bank, for the tanks could be slung from the A frame so that they would not only launch themselves but would lighten the draft of the whole unit in shallow water.[1,37]

12.15 AMPHIBIOUS PADDLE-WHEEL TOWBOAT

In May 1941, designs were prepared for an amphibious paddle-wheel towboat which could cross land and operate in water,[a] and could be used on towing barges proposed for ferrying tanks weighing as much as 90 tons.[1]

One design is shown in Figure 24. This calls for constructing the towboat in two longitudinal, mirror-image halves for easier handling and transport. Each half would be 20 feet long and 7 feet 10 inches wide, and would include a paddle wheel at the side. The wheel would be chain-driven by a 4-cylinder, 55-hp Ford automobile engine, with the controls brought to the inner side. The two units would be joined by means of special connectors.

In an alternate design, as shown in Figure 25, the paddle wheel would be fully contained within the hull of each unit, giving an over-all width of 5 feet.

In either case, although the boat is very heavy and requires two motors to maintain maneuverability, it should provide good towing power.

12.16 TANK LANDING SHIP

A 600-foot transport vessel was designed in May 1941 to serve as a tank landing ship. As shown in Figure 26, it would accommodate up to 82 30-ton tanks or a lesser number of amphibious tanks on a tank platform deck and in the hold.

A launching ramp at the after end of the ship would permit the tanks to be landed on suitable piers or barges, or amphibious tanks could be launched directly into the water.

[a] See following section.

[a] The [illegible]

The vessel would have a beam of 65 feet, a draft of 22, a depth of 42, and a speed of 20 to 22 knots. Antiaircraft guns would be mounted on the weather deck, and catapults would be provided to launch fighter planes. Shop facilities would be provided for repairs on the tanks during transport.[17]

This project was not carried beyond the preparation of rough plans, primarily because of a lack of interest by the Armed Services and because of their failure to agree on which branch should bear the responsibility, if any, for transporting tanks from ship to shore. At the time of this project, with no appreciation yet displayed by the Services for the actual requirements of an amphibious operation, Navy offices advised NDRC that the Army had not signified any intention to land tanks from ships, while Army offices asserted that such a requirement was a Navy responsibility. The research project was accordingly terminated.

Unknown to NDRC at the time, however, the

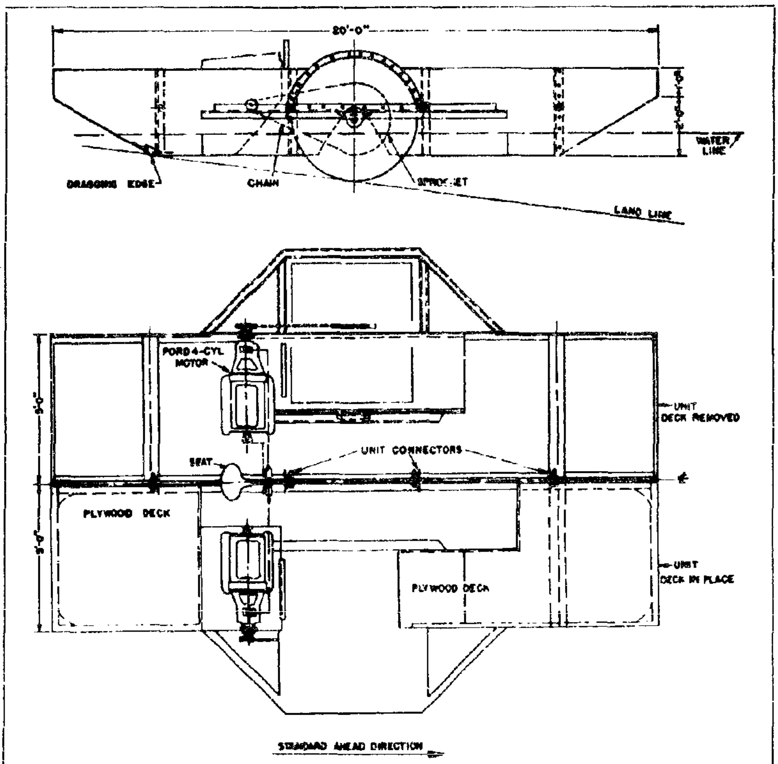

FIGURE 21. Amphibious paddle wheel towboat, plan 1.

basic idea of the tank landing ship had already been worked out by the British in the design of the LST (1) (Landing Ship, Tank, Class 1), and incorporated in the HMS TANGSTER and BOXER. Later, the LST (1) was redesigned and the idea of the tank landing ship found its final expression in the LST (2), which, at British insistence, was put into production by the U. S. Navy. The development of amphibious tanks is described in Chapter 9.

12.17 LANDING PIER

For the landing of 30-ton tanks at sites where tides up to 20 feet exist, a pier was designed with the main carrying members consisting of H-10 truss sections joined by connectors already developed for use in a ponton bridge, and the erection floats being the available standard 25-ton aluminum pontons.* The general plan is shown in Figure 27.

A section of pier with a length slightly more than 50 feet and with one bent attached would be floated into position. A crane operating on the already completed portion of the deck and a floating derrick would then raise the section from the pontons to the final elevation in the pier. After a connection was made to the completed portion and while the heavy end was still held by the derrick, the columns (until then in a raised position) would be dropped to the

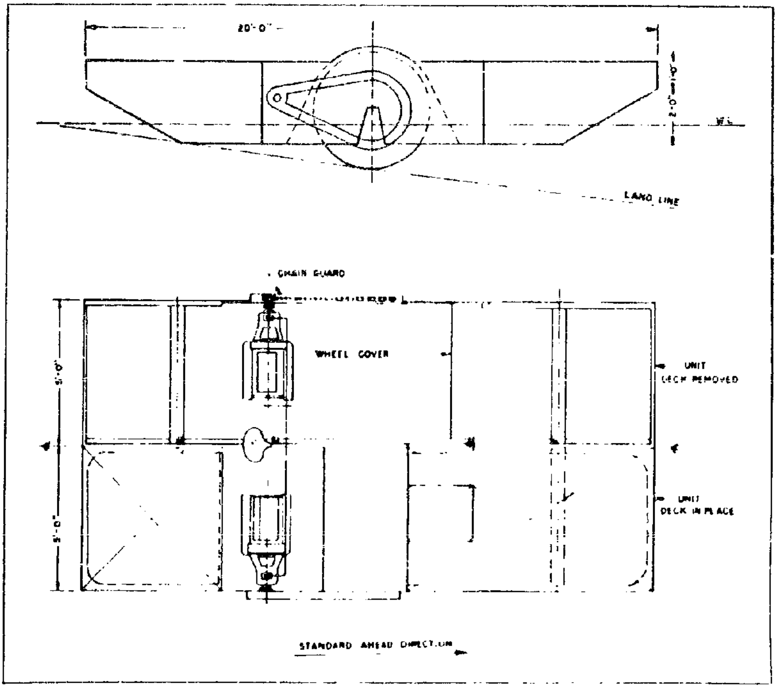

FIGURE 25. Amphibious paddle wheel towboat, plan 2.

bottom, and pins inserted at the transom ends. The next section of the pier would then float into position.[15]

12.10 QUAY REPAIRS

With the expectation that the U. S. Army would probably be called upon to put back into service many quays that were severely damaged by the withdrawing enemy, a study was made of the most useful designs.[a] The most practical is shown in Figure 28.

Wide-flange steel shapes, serving as piles, would be driven on 16-foot centers in two directions. The piles would next be flame cut to the desired elevation and caps, prepared in advance, placed on the piles and welded to take the entire load. The piles would be located with their flanges normal to the quay face in order to permit the easy installation of welded bracing at low tide. In cases where the pile bearing is inadequate, short pieces of the same section can be welded to the pile to provide added bearing.

The same size members which serve as piles can also be utilized as girders and welded to the column caps. A splice can be applied to permit the use of odd-length pieces of girder.

A number of alternate floor systems were considered:

1. A design using timber stringers and timber deck.

2. A design using steel stringers and an open steel floor.

3. A design using a reinforced-concrete deck on reinforced concrete stringers.

4. A design similar to 3, except that a lightweight joist is encased in the beam. This will support the forms and carry the wet concrete, thus eliminating the need for other form support.

5. A design using a reinforced-concrete deck on steel stringers. Corrugated iron sheets will serve as bottom forms for the slab and will be left in that position.

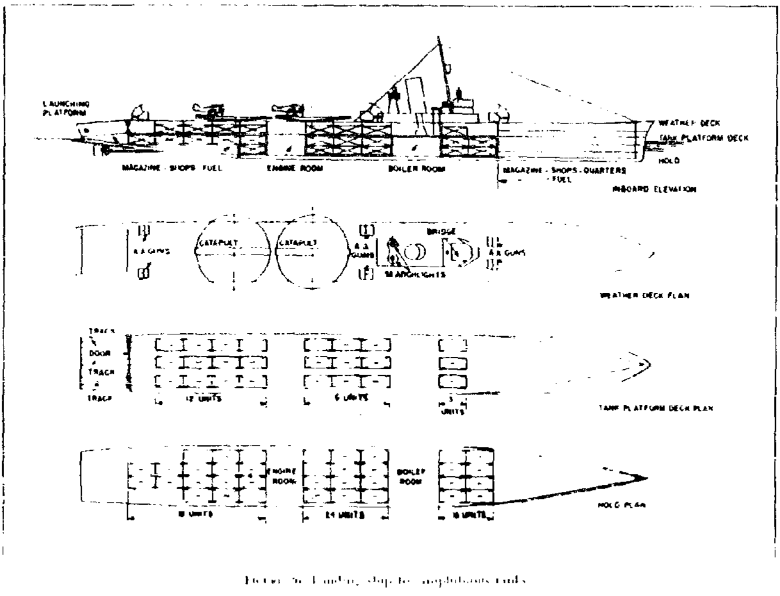

Figure 29. Landing ship for amphibious tanks

With any of these suggested floors, the basic design will serve with a tidal range of 10 to 12 feet and a low-water depth of as much as 30 feet, and may be contrasted with the British V-type trestle which was considered for the same service and which has a corresponding low-water depth of 16 feet.

Quays and piers similar to the suggested design have been satisfactorily used for a number of years, and experience with them indicates that they are adequate for docking large ships. This structure will support a medium tank and any wheeled vehicle except a loaded tank retriever.[16]

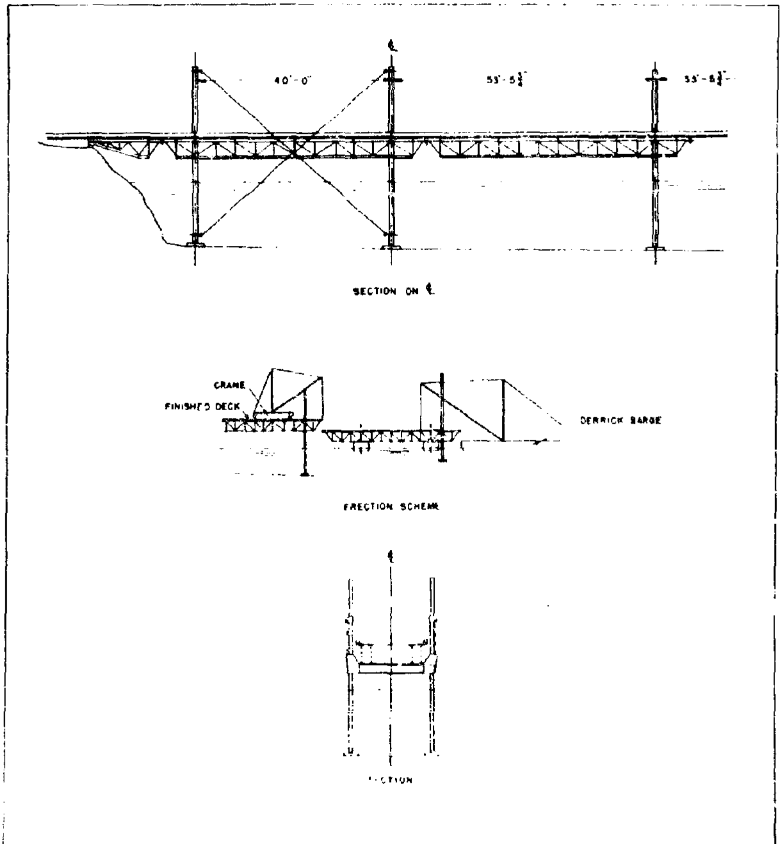

FIGURE 25. Design of [illegible] pier

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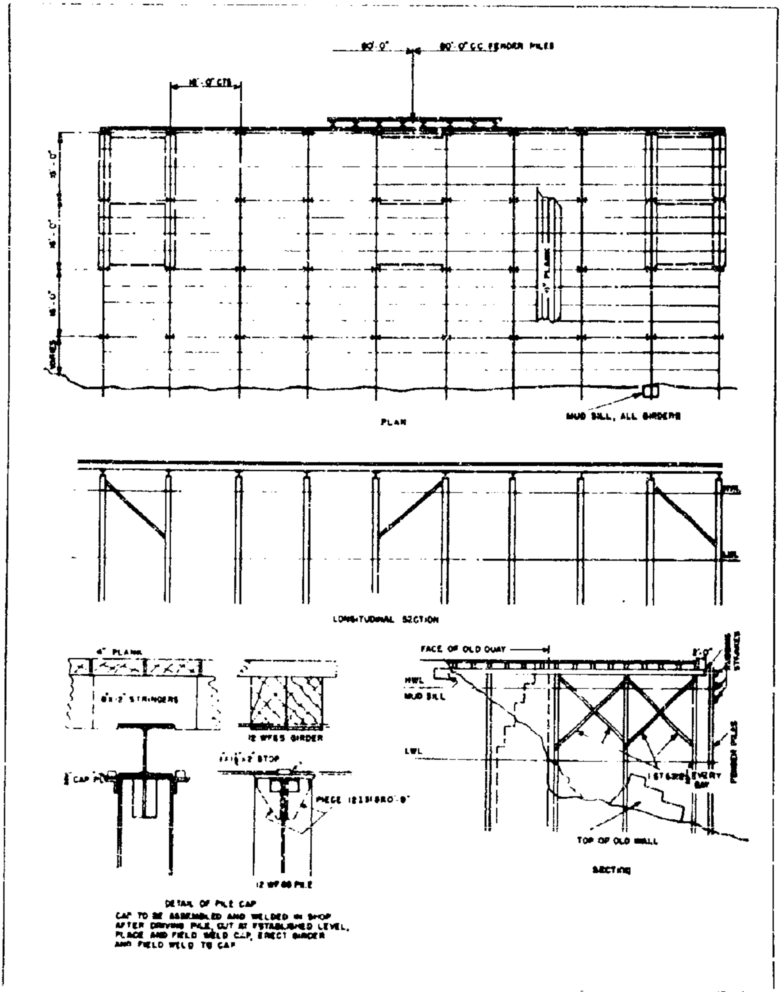


FIGURE 28. Proposed structures for quay repairs

Chapter 13

TESTS OF BRIDGE COMPONENTS

Summary

Analysis of balk, balk fasteners, and bolts used or contemplated for military bridges was conducted at the request of the Engineer Board of the U.S. Army Corps of Engineers.

Standard laboratory tests were performed on Douglas fir balk intended for ponton bridges, steel balk with and without web holes, and several designs of aluminum balk, including hollow balk and balk reinforced with internal ribs and traffic plates.

Similar tests were performed on welded steel, cast steel and bronze balk fasteners, and on heat-treated bridge bolts.[a]

13.1 TESTS OF DOUGLAS FIR BALK

Samples of Douglas fir balk intended for ponton bridges were tested as beams and for compression, both dry and after immersion in water. The beam tests were made on full-size balk with third point loading, and measurements were made of mid-point deflection and top fiber strains. These showed an average ultimate strength of 8,500 psi and a modulus of elasticity of 1,900,000 psi from mid-point deflection and of 2,159,000 from top fiber strain.

Smaller samples were tested in compression parallel to the grain, with some tested dry and others after being immersed in water overnight. This gave an average ultimate strength of 6,030 psi and a modulus of elasticity of 1,925,000 psi for the dry samples, and 5,650 and 1,860,000 for the wet samples. A gain in moisture of about 9 per cent by weight was found to decrease the strength and stiffness considerably. No correlation was found, however, between per cent increase in moisture and per cent decrease in strength and stiffness. Similarly, an effort to correlate specific gravity to strength and stiffness gave no definite relationship. The number of annular rings per inch does not prove to be related in any orderly way to strength and stiffness.

Other tests seemed to indicate that balk with the growth rings vertical have slightly higher proportional limits and moduli of elasticity, but slightly lower ultimate strengths than those with rings horizontal.[3]

13.2 TESTS OF ALUMINUM BALK

Aluminum Alloy (R305-T315)

In order to determine their usefulness as balk for a floating bridge, welded members of aluminum alloy R305-T315[b] were tested for yield strength and ultimate strength.

Of eight samples, five failed at stresses of 6,220 to 8,200 psi with the break at the edge of a $\frac{5}{16}$-inch weld, while three failed at stresses of 5,550 to 7,410 psi with the break in the weld. In shear tests, five of six samples failed at the edge of the weld at stresses of 3,200 to 4,020 psi. In all these cases the parent metal failed at stresses exceeding 33,000 psi. One plain specimen of the alloy gave a yield strength of 73,400 psi, an ultimate strength of 77,200, and a modulus of elasticity of 10,000,000 psi.[4]

Beams With and Without Web Holes

A steel beam with lightening holes cut in the webs to reduce dead weight was investigated to determine the effect of the holes on beam deflection. The holes, $3\frac{1}{2}$ inches in diameter, were cut along the center line of the web at $6\frac{1}{2}$ inches center to center, in an 8-inch WF 17-pound steel beam. The beam was tested both before and after the holes were made.

The solid web was loaded with 20,000 pounds at a calculated fiber stress of 15,200 psi without giving any permanent set. The web with holes was tested up to 25,000 without failure and without permanent set upon return to initial loading.

Deflection measurements showed an increase of center deflection for the beam with holes of about 0.01 inch per 8,000 pounds over the beam without holes. The beam with holes held the maximum load imposed without apparent distress.

The total load was limited by a desire to keep flange bending stresses below the yield strength

[a] These tests were conducted by the Drexel Institute of Technology, Philadelphia, Pa., under OSRD contract OEMsr-[illegible].

[b] Manufactured by Reynolds Metals Company. Test welds made by [illegible] Steel Manufacturing Company, Phoenix, Ariz.

values. The shearing stress in the web due to the largest load placed on the beam without holes was therefore only 5,150 psi. This is less than one-half of the peacetime allowable shear stress of 11,000 psi in the webs of highway bridge girders, which in turn is far below the value which causes buckling failure.[5]

Balk (24S-T) with Internal Rib

A normal 9x9 inch aluminum balk of alloy 24S-T[c] was subjected to a beam test of the balk, tension and shear tests of the welds, and a tension test of the aluminum. The balk (Figure 1) was made from two aluminum channel-shaped extrusions, welded to form a box-shaped section. The top has six external longitudinal ribs and one internal longitudinal rib. In the external ribs, indentations are pressed 1½ inches center to center. These indentations are opposite in alternate rows, staggering those in the other three rows, and are of such a depth that the inside of the top becomes level directly beneath them.

As the loading increased, an apparent elastic limit

[c] Fabricated by the Allison Steel Manufacturing Company, Phoenix, Ariz.

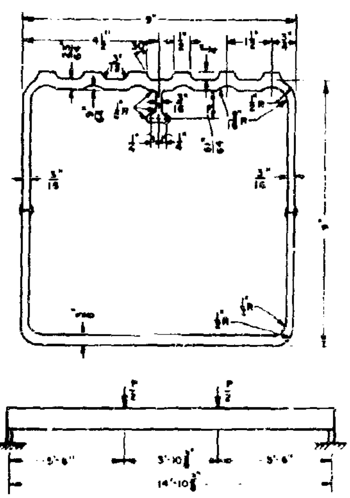


FIGURE 1. Cross sec[illegible] aluminum deck balk with internal rib with det[illegible] beam test setup.

was observed between 30,000 and 32,000 pounds. No visual signs of failure were noticed below 46,000 pounds. Definite failure occurred at 51,800 pounds, with buckling of the webs and the upper plate.

In tension tests, the weld failed under an average breaking load of 8,170 pounds or 4,090 pounds per inch of weld, in contrast to 21,680 psi for the parent metal. In shear test, the weld failed under an average breaking load of 12,550 pounds or 3,150 pounds per inch of weld, in contrast to 33,730 psi for the parent metal.

In tension tests of the aluminum, the yield strength was found to be 50,700 psi, the ultimate strength 68,000, and the elongation was 14.21 per cent in 8 inches.[13]

Normal Balk (61S-T) with Reinforcing Plates

A normal 9x9-inch aluminum balk of 61S-T alloy was subjected to a beam test of the balk, tension and shear tests of the weld, and a tension test of the aluminum.

The balk was made from two channel-shaped extrusions, with plates riveted to the top and bottom, symmetrical with the center of the balk and extending on either side. The rivets on the plates were staggered. The channels were then welded to form a box-shaped section (Figure 2).[e]

As the load was applied for the beam test, the first indication of permanent set came at 34,000 pounds, with a definite set observed at 35,000 pounds. Sudden failure came at 50,900 pounds, with buckling of the top plates and webs.

In tension tests of the weld, failure occurred at an average of 4,150 pounds per inch of weld, in contrast to 23,000 psi for the parent metal. In shear tests, the weld failed at an average of 2,690 pounds per inch of weld, in constrast to 27,700 psi for the parent metal.

In tension tests of the aluminum, the average ultimate strength was found to be 43,600 psi and the average elongation 9.92 per cent.[10]

Normal Balk (61S-T) with Internal Rib

A 9x9-inch aluminum balk made from two aluminum channel-shaped extrusions of alloy and welded to form a box-shaped section (see Figure 1) was subjected to a beam test of the balk, tension and shear tests of the weld, and a tension test of the aluminum.

The top has six longitudinal external ribs and one internal rib. In the six external ribs, indentations

1¼ inches long are pressed 4½ inches center to center. These indentations are opposite in alternate rows, staggering those in the other three rows, and of such a depth that the inside of the top becomes level directly beneath the indentations. The plane of the ribs in the two outer rows is slightly above that of the ribs in the four inner ones.

As the loading was increased, an apparent elastic limit was observed at approximately 32,000 pounds. Failure occurred with a 40,000-pound load, with definite buckling in the webs and in the upper plate.

In tension tests of the weld, each specimen failed in the weld with an average value of 1,140 pounds per inch of weld. Those welds showed very poorly fused metal, which explains the low values of the breaking loads.

In shear tests, average shear value was 2,440 pounds per inch of weld, with a minimum of 2,340 pounds per inch.

In tension tests of the aluminum, the average ultimate strength of the specimens was found to be 42,970 psi and the average elongation 10.96.[8]

HEAVY BALK (61S-T)

A heavy 9x9 inch aluminum balk of alloy 61S-T was subjected to three sets of tests, including beam tests of balk, tension and shear tests of welds, and tension tests of the aluminum.

The balk (Figure 3) was made from two channel shaped extrusions welded to form a box shaped section. The top surface has five longitudinal ribs in which 1¼ inch indentations are pressed opposite each other in alternate rows; those in the other three rows are staggered; and all are of such a depth that the inside of the top becomes level directly beneath them. The plane of the two outer ribs is slightly above that of the three inner ones.

In the initial group of tests, the first indication of a permanent set under increased loading came at 26,000 pounds, with a definite, measurable set after the 30,000-pound load. No visual signs of failure were noticeable below 38,000 pounds, and buckling occurred in the webs and upper plate at 40,000.

The weld failed in tension tests at an average of 2,740 pounds per inch of weld, in contrast to 14,150

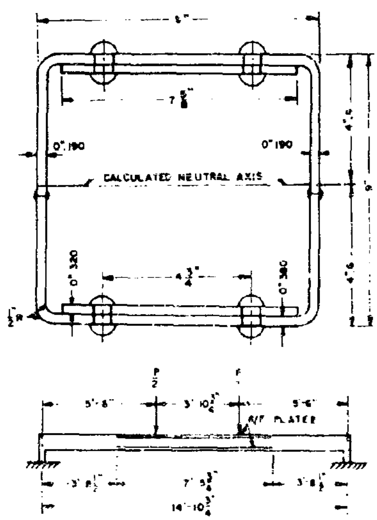


FIGURE 2. Aluminum balk reinforcing plates with details of beam test setup.

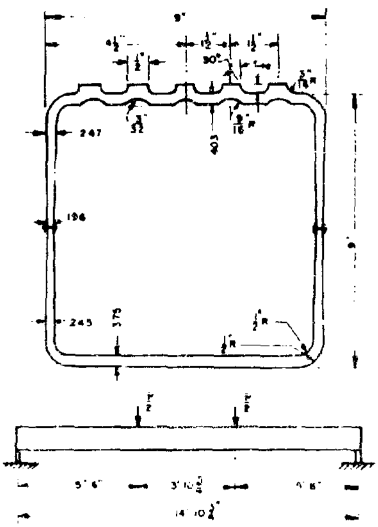


FIGURE 3. Heavy aluminum balk of 61S-T with details of beam test setup.

psi for the parent metal, and in shear tests at an average of 2,910 pounds per inch of weld, in contrast to 28,400 psi for the parent metal.

The average yield strength of the aluminum was found to be 39,500 psi, the ultimate strength 41,600 psi, and the per cent of elongation 11.50 in 8 inches.[7]

In the second series of tests, the first indication of a permanent set under increased loadings came between the 28,000- and 30,000-pound loads, with failure at 40,200 pounds marked by buckling of the webs and top plate at one of the loading points.

Under tension, the weld failed at an average breaking load of 9,670 pounds or 4,800 pounds per inch of weld. In comparison, the parent metal failed at 23,900. In shear tests, the weld failed at an average breaking load of 10,500 pounds or 2,620 pounds per inch of weld. The average unit stress in the parent metal at failure was 26,200 psi.

In a tension test of the aluminum, the results gave an average ultimate strength of 42,500 psi and an elongation of 10.88 per cent in 8 inches.[8]

USED BALK

A used welded aluminum balk reported to have had approximately 1,000 passes of an M-4 tank with steel tracks[1] was subjected to a beam test of the balk, tension and shear tests of the welds, and a tension test of the aluminum.

The balk consists of two aluminum channel-shaped extrusions of 61S-T alloy, welded to form a box-shaped section (Figure 4).

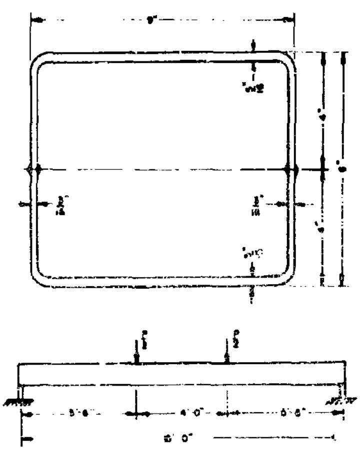


Figure 4. Used aluminum balk with details of beam test setup.

The first indication of permanent set came at or near 19,000 pounds. At a load of slightly less than 26,000 pounds, failure occurred with the buckling of the top flange at one of the loading points. This buckling increased to such an extent that only 19,000 pounds could be maintained by the balk. At this final load, the center line deflection was 3.05 inches, with a set of 0.90 inches upon release of the load. Since the buckling of the top flange occurred before the yield strength stress was developed, the balk had apparently not been damaged by its previous usage.

The weld failed under tension at an average of 3,620 pounds per inch of $\frac{5}{16}$-inch weld, with a minimum of 1,680 and a maximum of 3,750, in contrast to an average of 13,590 psi, a minimum of 8,820, and a maximum of 19,250 for the parent metal. Under shear, the weld failed in two of four samples at an average of 980 pounds per inch of $\frac{5}{16}$-inch weld, in contrast to an average of 10,270 psi for the parent metal.

Tension tests on the aluminum gave an average yield strength of 39,680 psi, a maximum stress of 42,500, and a 9.37 per cent elongation in 8 inches. It was noted that the wearing of the top flange of the balk did not affect its maximum stresses, which were slightly greater than the maximum values for specimens taken from the bottom flanges.[8]

BALK WITH TRAFFIC PLATE

A welded aluminum balk with steel traffic plate[4] designed for use on bridges and other structures was submitted to beam tests of the balk itself, tension and shear tests of the welds, tension tests of the aluminum and the traffic plate, and pull tests on the balk lugs.

The balk (Figure 5) is composed of a steel traffic plate riveted to a box-shaped section made from two aluminum extrusions of alloy 61S-T joined by welds formed by a Lincoln carbon arc machine, tornado head.

The beam tests on a 15-foot simple beam indicated an apparent elastic limit at or near 22,000 pounds.

[4] Designed by Sparkman & Stephens, Inc., New York, N. Y., and fabricated by the Allison Steel Manufacturing Company, Phoenix, Ariz.

with a center deflection of 3.75 inches under a maximum load of 30,600 pounds. Deflection is a straight line function of the load until the elastic limit of the steel is reached. Further analysis indicated that the permanent deformation of the steel prevents the aluminum in the vicinity of the steel plate from returning to its original length. The stresses in the aluminum do not reach elastic limit values even at a beam load of 28,000 pounds.

In accordance with beam theory, the unit strain in the aluminum, measured at various distances from the calculated neutral axis, varies directly with the distance. A shift in the position of the neutral axis is noted first at the 22,000-pound load and, as expected, is toward the stronger side of the beam and away from the compression side, where failure starts.

Tension tests 90 degrees to the weld resulted in five failures in the weld, with a minimum value of 2,170 and an average of 3,200 pounds per inch of weld, and eight failures in the plate. Tension tests 45 degrees to the weld gave a minimum shear value of 1,270 and an average of 2,110 pounds per inch of weld.

Tension tests made with a Huggenberger strain gage on specimens of aluminum and traffic plate gave the following results:

Specimen	Yield strength (psi)	Maximum (psi)	% elongation in 8"	E
Aluminum	36,700	40,300	9.62	10,600,000
Traffic plate	36,300	53,500		
Traffic plate	39,200	51,500	25.5	

Tests were performed to determine the pull in direct tension which the intermediate lugs would resist. One specimen failed at a load of 37,400 pounds when the weld metal connecting the lug and the two bolts on one side of the fitting sheared off. The second test was stopped after the other lug had resisted a pull of 37,500 pounds without failure.[3]

Hollow Metal Balk

Tests performed on samples of hollow metal balk* proposed as lightweight beams for use in ponton bridges and other structural devices showed that the members are too weak in shear to allow the development of beam strength.

The hollow balk weighs 8¾ pounds per foot and is in the general shape of a hollow I section. The flanges consist of channels 3.30 inches back to back of flanges. The web consists of two plates, 0.07 inch thick and spaced 1.78 inches apart, bent to fit around timbers 1x3 inch used to shape the flanges. The channels are tack-welded along the edges to the web metal and also are spot-welded through the top of the flange. The web has holes 5.5 inches in diameter on 9-inch centers, the two side plates bent in and welded together to form the holes.

Strain measurements showed that the material does not bend as a beam, and finally fails due to shear as indicated by the buckling of the web metal between the holes, the distortion of the holes, and the flat straight shape of the member between loading points. Tension tests showed a definite yield point for the flange, marked by both scaling and the drop of the beam at 27,300 psi. The ultimate stresses are 41,700 psi for the flange and 17,200 for the web.[3]

15.5 TESTS OF BALK FASTENERS

Three types of balk fasteners were examined at the request of the Engineer Board, and tested for resist

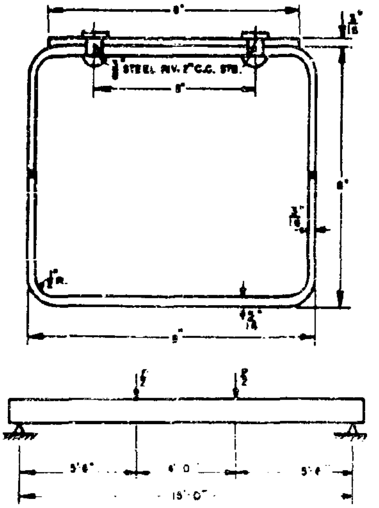


FIGURE 5. Aluminum balk [illegible] steel traffic plate [illegible] of beam on test setup.

* Manufactured by the Ralley Machine Co., Belleville, N. J.

ance to various loads and for operation of the fastening mechanism.

Welded Steel Balk Fasteners

Two specimens were subjected to loads up to 13,500 pounds. One specimen began to yield locally near the hook at 11,500 pounds and failed at 13,500. When the end of the locking pin was ground to a conical point to facilitate the drifting together of the parts, the mechanism operated satisfactorily after holding a load of 13,000 pounds. The second specimen held a maximum load of 13,300 pounds, with the mechanism operating satisfactorily throughout.[12]

Bronze Balk Fasteners

Specimen fasteners for 10- and 25-ton ponton bridges were tested for maximum load and for workability of the ratchet mechanism after successive loads. The fasteners designed for the 10-ton bridge failed under an average load of 11,000 pounds, with the mechanism locking at 9,500. Those for the 25-ton bridge failed under an average maximum of 18,290 pounds, with the mechanism locking at 13,330.[14]

Cast Steel Balk Fasteners

Five cast steel fasteners were tested for maximum load and for workability of the mechanism, with failure occurring at an average of 16,500 pounds. Each failed suddenly at a section near the hook.[14]

19.4 TESTS OF BRIDGE BOLTS

Heat-Treated Bolts

Heat-treated steel bolts[c] designed for use in the light H-10 portable bridge were tested with two different types of threads. The bolts have a nominal diameter of 1½ inches, an over-all length of 22 inches, a thread length of 3 inches with five threads per inch, and a square head 1 inch high and 1$\frac{15}{16}$ inches flat diameter.

Ten bolts, five made with Acme threads and five with Dardelet threads, were supplied with mild steel hexagonal nuts and tested full-size for yield point and ultimate strength with a distance of 19 inches from under the head of the bolt to the inside bearing of the nut. This is the distance generally used in service.

With Acme threads, all bolt failures were in tension at the minimum cross section next to the nut, with a cross-section area of 0.811 square inch. The bolts failed at an average of 154,240 psi, giving an average maximum unit stress of 154,240/0.811 or 190,000 psi.

With the Dardelet threads, three failures occurred in the nut threads at a maximum unit stress of 114,400, 143,900, and 149,600 psi, respectively, one in the bolt threads at 166,700, and one partly in the bolt threads and partly in the nut threads at 165,400.

If heat-treated bolts are used with the H-10 bridge, it is recommended that the bearing lugs of the bridge be torch hardened and the hole reduced from 1½ to 1⅝ inches.

The threads of the 1½-inch mild steel nuts as supplied were found to shear out at an average maximum load of 116,750 psi. To realize a value equaling that of the bolts, the nuts should be made 2 inches long (1¾ inches if heat treated).[15]

[c] Manufactured by the Lamson & Sessions Co., Cleveland, Ohio.

Chapter 14

TORPEDO PROTECTION FOR MERCHANT VESSELS[a]

Summary

At the request of the U. S. Maritime Commission, improved wire nets have been developed to protect merchant vessels from torpedo attack. One type of net, weighing 11 tons, can be carried by ships under way with the aid of handling gear weighing 16 tons, and is able to catch 30- to 35-knot torpedoes by their tails. Another, which can either be carried by the ships or be placed around them while moored, is able to stop 45- to 50-knot torpedoes by their heads.

New net designs have been prepared, new wire strand specifications made, and new streamlined metal clips devised to give maximum efficiency, maximum useful life, and minimum drag through the water. The drag of a Liberty ship at 11.5 knots has been reduced from about 1.6 knots to about 1.3 knots, thus permitting such a vessel to maintain convoy speed in a 10-knot convoy, with her nets down. The reduction in shaft horsepower absorbed by the net is about 110, from 900 shp to 790 shp.

Electrically energized cables have been developed for use with these nets as a protection against magnetic torpedoes. The energized cables are designed to produce a magnetic field which will explode such torpedoes before they reach their target.

All these devices have been tested *full scale* in a limited number of field trials and appear to operate successfully.

There is no doubt that ship losses could have been averted had net protection been developed 2 years earlier, had ships been equipped with this gear, and had ship's masters been compelled to use it in waters where submarines might be operating. With the latest type of net developed in this investigation, ships can remain at anchor in comparative safety or can move in 10-knot convoys.

Although the various laboratory and field tests left little doubt that the newly developed nets were considerably superior to the older type, the new device was not placed in production. It was felt by responsible officers of the U. S. Maritime Commission that any change of design would delay delivery, necessitate the scrapping of much material, and increase the cost of manufacturing. In addition, it was decided, submarine warfare did not at that time warrant such a change.

The need for a defense against magnetic mines was not considered to be urgent, and consequently no practical applications of the electrically armed cable were made.

Despite the added effectiveness of the improved clip designs, these were not used because of the decision that their adoption would result in scrapping both machinery already delivered and old style clips already manufactured, and in an increased cost of manufacture, without a sufficient degree of improvement.

The Coordinator of Ship Defense Installations of the U. S. Maritime Commission has, however, forwarded to Division 12, with approval, a letter from

[a] Project "Merchant," NO-158.

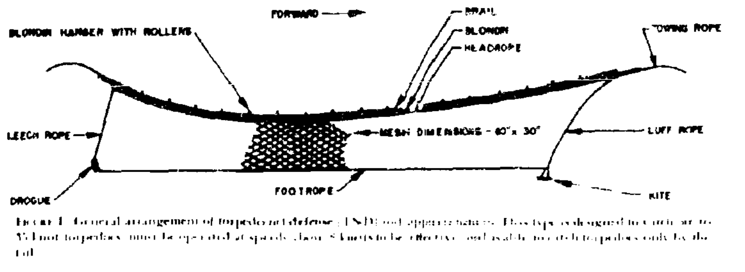


FIGURE 1. General arrangement of torpedo net defense (NSD) and approximate [illegible]. This type is designed to catch 30- to 35-knot torpedoes, must be operated at speeds above 8 knots to be effective, and is able to catch torpedoes only by the tail.

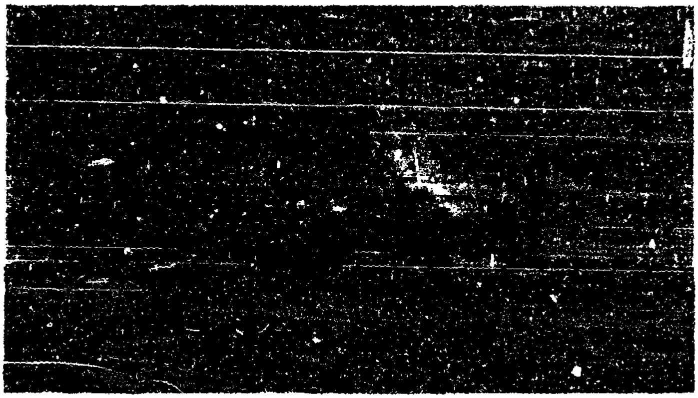


FIGURE 2. Nets streamed on Liberty ship.

the Director, U. S. Maritime Commission Depots, stating that the development expense, some $250,000, was justified.

14.1 THE PROBLEM

Ever since the use of submarines in World War I, methods had been sought for efficient protection against them, particularly for merchant vessels which were unequipped with necessary submarine detecting devices and antisubmarine weapons, and which were too slow to evade attack. Early in 1943, when no satisfactory solution had yet been found for the German submarine campaign in World War II, the U. S. Maritime Commission requested assistance in developing adequate net protection for EC-2 Liberty ships. These vessels were already being equipped with Torpedo Net Defense [TND], which had been developed by the British as an emergency measure in World War II and which was still in a somewhat experimental stage. The nets were difficult to handle, had a short life, and caused a high water drag, with the result that ships masters and convoy commodores were often reluctant to stream them, particularly since Liberty ships were consequently slowed down by about 2 knots or just enough to be forced out of the 10-knot convoys and into the slower convoys.

A research program was consequently set up in May 1943 to investigate three protective devices:[b] (1) a net to catch low-speed (30- to 35-knot) torpedoes by their tails, (2) a net to stop, catch, or deflect high-speed (45- to 50-knot) torpedoes by their tails or heads, and (3) a device to give protection against magnetic torpedoes.

[b] This investigation was conducted by the American Steel and Wire Company, New Haven, Connecticut, under OSRD contract OEMsr-1077.

FIGURE 3. Nets hauled on Liberty ship.

In the case of complete nets, an attempt was made in the design to decrease the net drag at cruising speeds, increase the operating life of the mesh strands, often limited to one round trip across the Atlantic, and simplify the manufacture of the components.[4]

14.2 PROTECTION AGAINST LOW-SPEED TORPEDOES

14.2.1 Procedure

Nets first went into service on American Liberty ships in November 1942. These were similar to those currently being installed on British merchant vessels, with a complete defense consisting of two nets, one provided for each side of the ship (Figure 1). Each net[b] is about 270 feet long and extends below the water surface approximately to the draft of the ship.

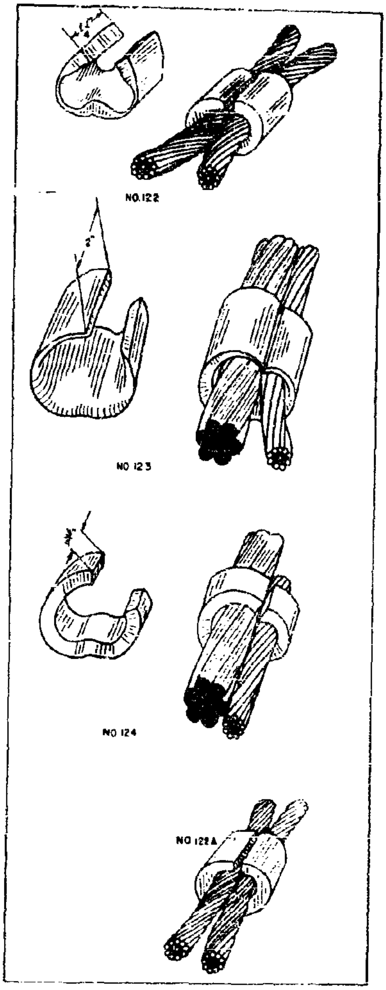


FIGURE 4. New clips designed for antitorpedo nets.

FIGURE 5. Recovery of low-speed torpedo caught in net.

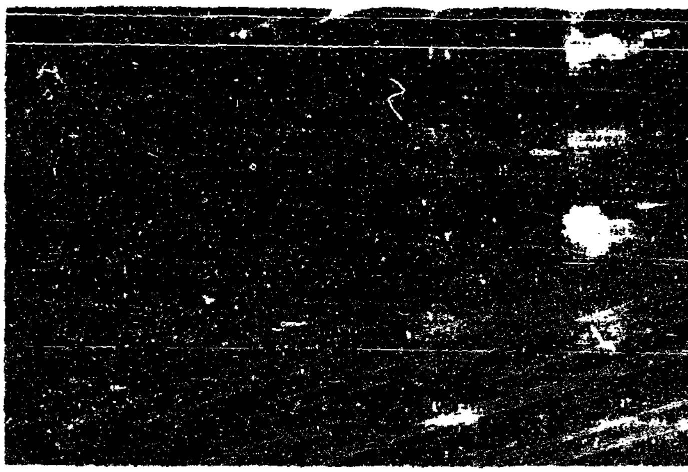


FIGURE 6. Sequence of views showing approach of low-speed torpedo and its capture by the tail in a diamond mesh weave net. Successive frames reading downward in each column show torpedo nose passing through the mesh until tail is caught. White line crossing the lower left hand corner of each frame is the after guy of the forward boom. White disturbance in water entering at right of frame is wake of net, the forward end of net being toward left. Torpedo was held until its fuel was exhausted. These pictures represent alternate frames taken from moving picture film at speed of 16 frames per second. Period covered by this sequence is approximately 4 seconds.

When the net is streamed (Figure 2), it is supported by Blondin rollers on a Blondin cable which is attached to the ends of tubular steel booms so that the net takes a vertical position about 50 feet from the ship's side.

These early nets are composed of $^{5}/_{16}$-inch diameter, 19-wire strands with a minimum breaking strength of 11,500 pounds, woven together and attached by riveted clips to form a diamond-shaped mesh 60 inches long and 30 inches high. The strands are also clipped to four boundary ropes: the head rope above, the footrope below, the luff rope forward, and the leech rope aft.

The Blondin cable supports the net so that, with the assistance of a kite attached forward and a drogue attached aft, the net is held in a vertical position when moving through the water. Each boom supporting the net is held in a horizontal position by a topping lift rove through blocks at the masthead.

When the net is brailed or taken in, a brailing rope gathers the net and its roller supports to the end of the after boom; both booms are then raised vertically until they engage a device which secures them to the mast arm, and the nets hang free from a point about

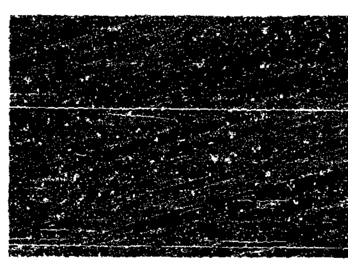


FIGURE 7. Hole in diamond weave net which has been struck by high speed torpedo.

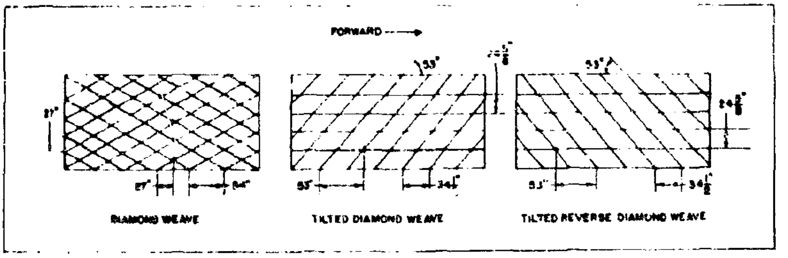


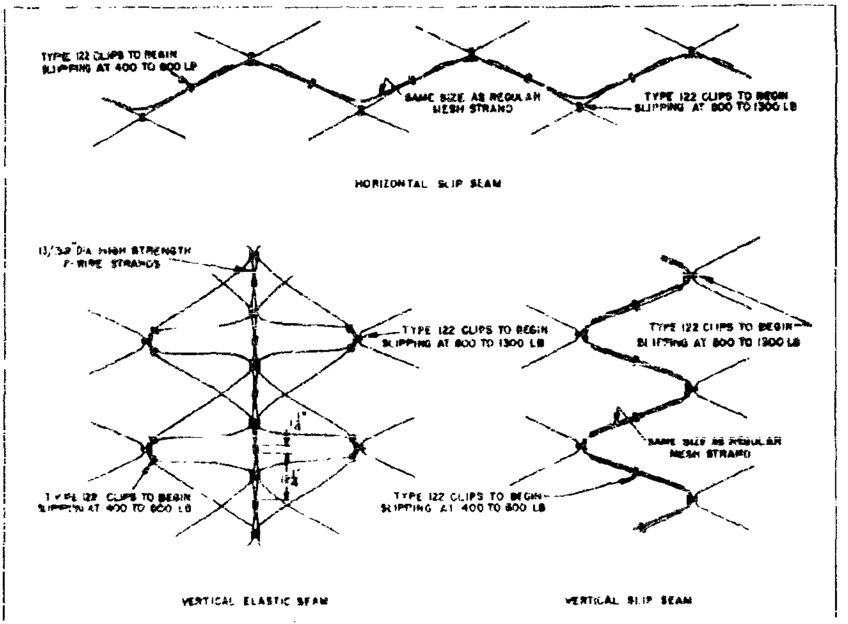
Figure 8. Diagrams of diamond, tilted diamond, and tilted reverse diamond weave.

70 feet above the deck, where they are lashed in position by means of a wire rope gasket (Figure 5).

The nets are streamed along the Blondin by means of a towrope when the booms are lowered sufficiently [illegible] the nets to clear the decks.

The necessary power for these operations is derived from the ship's cargo winches.

Some of these nets already in service were examined and their components subjected to laboratory test. It was found at the U. S. Maritime Commission



[illegible]

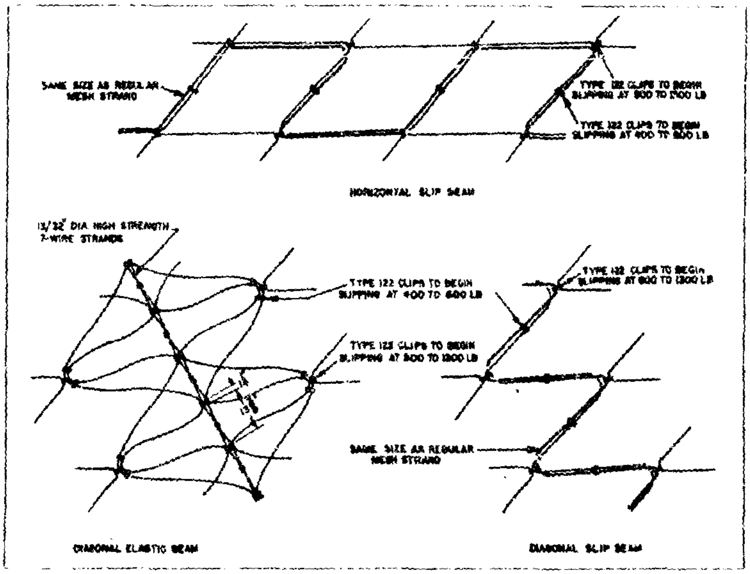


Figure 39. Details of seams in tilted diamond weave.

Brooklyn Depot that the most noticeable failures were due to the corrosion of the strand and the connecting clips, and to the strands being pulled from the boundary rope clips during service. The strand wires were failing from fatigue, particularly at the points where they were clipped together to form the mesh.

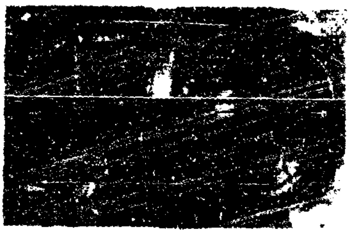


Figure 38. Laboratory setup to determine wire strand necessary to entangle and hold torpedoes. Test wire shown held firmly in frame is moved into propeller.

These findings were confirmed and amplified by laboratory tests which showed that the clips used in the net were unsatisfactory. They were ungalvanized and corroded rapidly. They had to be riveted together, a process which distorted, mashed, and weakened the strands. The slip value between the strand and the clip was not constant, varying greatly in the "break-away" value and in the "steadying-down" value.

Accordingly, three new types of galvanized, welded, streamlined clips, Types 122 and 122 A as mesh clips and Types 123 and 124 as boundary clips (Figure 41) were developed and incorporated in a net with standard 60x30-inch mesh which was installed on a Liberty ship for test. With the ship

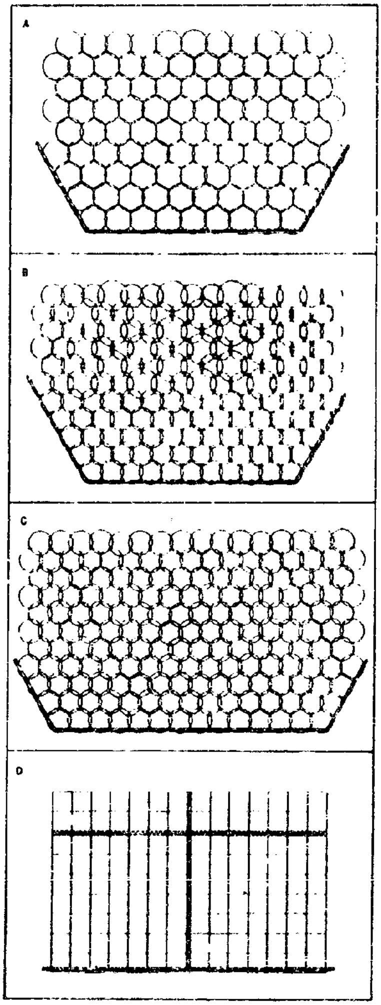


FIGURE 12

Design A was tested as 11/32-inch diameter, 19-wire strand, 16-inch diameter swaged grommets and as 5/16-inch diameter, 7-wire strand, 16-inch-diameter swaged grommets.

Design B was tested as 0.282-inch diameter, 0.097 wire, combination 12- and 16-inch diameter handwoven grommets and as 5/16-inch, 7-wire strand, combination 12- and 16-inch diameter swaged grommets.

Design C was tested as 0.312-inch diameter, 0.104 wire, 12-inch diameter swaged grommets.

Design D was tested as No. 000½ wire, 10x10-inch welded reinforcing mesh.

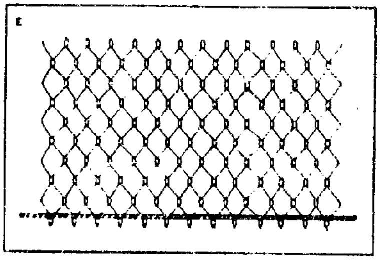


FIGURE 13. *Design E* was tested as ½-inch diameter, 19-wire strand and as 9/32-inch-diameter, 19-wire strand expanded weave, each section 11 inches square.

under way, 31-knot torpedoes equipped with collision heads were fired at the net. The ability of this net to stop torpedoes was noted, as was the drag of the net and the general arrangement and type of gear used to support and operate the nets.

14.8.2 Results

The new clips functioned satisfactorily while the nets were catching 31-knot torpedoes by fouling their propellers and tail assemblies (Figures 5 and 6). In those cases of failure which did occur in the test, the failure of the mesh strands at the leech rope was responsible.

Use of the new clips reduced the drag of two nets from 1.66 knots to about 1.30 knots. Ship's speed, normally 11.5 knots, increased from 9.9 knots with the standard net to 10.2 knots with the new net. The slip values of the new clips are relatively constant.

The mechanical gear used to support and operate the net was found not conducive to long rope life, and the arrangement of snatch blocks results in some hazard to personnel when the net is streamed in heavy weather.

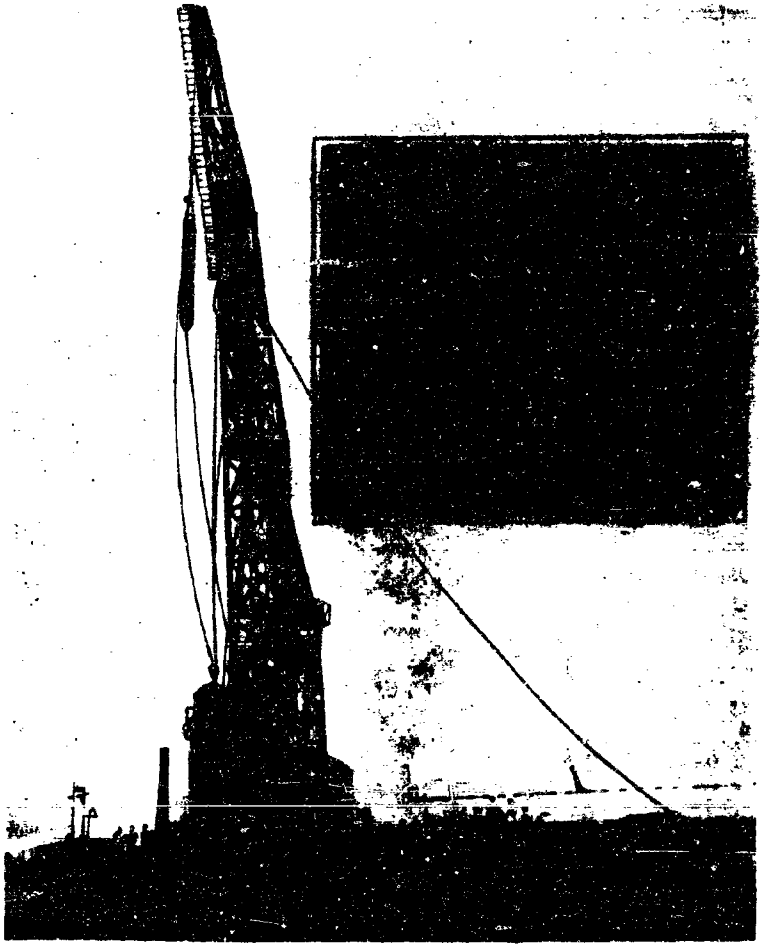


FIGURE 14. Setup for drop tests on proposed net designs. Inset shows dummy torpedo striking at 15 knots.

14.2.3 Conclusions

From these investigations, it appears that a net can be manufactured to provide excellent defense against 30- to 35-knot torpedoes by catching them by the tail. The new clips adequately support the net strands and give constant slip values so that the torpedo can be gradually slowed and then finally stopped. They should increase the life of the strands and, since they are streamlined, they permit at least slightly higher ship's speed.

The mesh strands should be galvanized to reduce corrosion, and they should be dead-ended at the leech rope. An $^{11}/_{32}$-inch diameter strand was recommended.

Although the mechanical gear used with the nets in these tests was not altogether satisfactory, it was decided that under the actual conditions prevailing it was not desirable to make changes.

Certain general specifications can apply to the clips, strands, and mesh of nets:

1. The clips should allow enough strand slip to *slow* the torpedo gradually, and their built-up holding power must then be sufficient to *stop* the torpedo.
2. The clips securing the mesh strands to the boundary ropes must allow the strands to slip when the torpedo impact forces reach them, but they must not allow slippage during normal handling or usage in a seaway.
3. The strands must have sufficient strength to absorb all energy remaining from the impact after a portion is dissipated by clip slippage.
4. The strands must also have sufficient flexibility to become properly enmeshed in the torpedo tail assembly, and sufficient toughness and abrasion resistance to survive the entanglement.
5. For improved operating life, the mesh strands, brail, and towing ropes should be impregnated with lubricant.

14.3 PROTECTION AGAINST HIGH-SPEED TORPEDOES

14.3.1 Procedure

In the first phase of this investigation, tests showed that an improved net could successfully stop relatively low speed (30- to 35-knot) torpedoes by entangling their propellers. It then became desirable to perfect similar methods for protection against

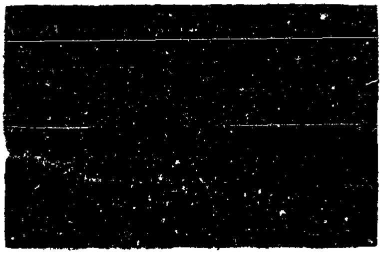


FIGURE 13. 27-knot torpedo striking expanded weave net with ship and net static.

relatively high-speed (45- to 50-knot) torpedoes. This was more difficult.[10]

Field tests quickly showed that at torpedo impact, the mesh strands were sheared by the propeller before they could entangle the propeller blades and shafts and bring it to a stop (Figure 7).

Several different types of diamond mesh, tilt diamond mesh, and reverse diamond mesh panels were substituted (Figure 8), and "seams" (Figures 9 and 10) were incorporated to absorb the impact more gradually, but these modifications did not offer more than minor improvement. In turn, all the contributing characteristics which had brought about successful tail catches of 35-knot torpedoes were extended in proper ratios, but every trial revealed that there was insufficient strand strength and net yield to stop the torpedo. Additional laboratory tests were conducted at the U. S. Naval Net and Fuel Depot, Melville, Rhode Island, to determine the minimum wire strand which could entangle and hold a high-speed torpedo (Figure 11), but it was found that the weight of this minimum strand would probably exceed the capacity of the ship's gear and that its towing resistance would be impractically high.[13]

In view of these unsuccessful endeavors, the investigation turned to the design of nets to catch or stop high-speed torpedoes by their heads, and at the same time to a study of the use of such nets to protect moored vessels as well as vessels under way.

Improved types of grommet nets and welded reinforcing mesh nets (Figure 12) and expanded weave nets with wire strand with fixed intersections (Figure 13) were fabricated and studied in torpedo drop tests.[11] Each net was supported horizontally by buoys and placed beneath a 3,650-pound Mark 14 dummy

torpedo. When this dummy was dropped from a height of 90 feet, its velocity at point of impact was 45 knots[c] (Figure 14). It appeared from these tests that an expanded weave net of $\frac{9}{32}$-inch diameter, 19-wire strands would withstand this impact.

Accordingly, experimental nets were constructed with $\frac{9}{32}$-inch and $\frac{5}{16}$-inch diameter, 19-wire strands and installed for sea tests with torpedoes equipped with collision heads.

[c] A mathematical analysis of the results is contained in reference 9.

14.3.2 Results

In trial runs[12] with the ship under way, the expanded weave nets successfully caught 47-knot torpedoes without damaging the net (Figures 15, 16, and 17). Decelerometers attached to each torpedo indicated the impact was absorbed so gradually that it was unlikely that the kinetic type of exploder mechanism would have been set off.

In a trial run with the ship dead in the water, the expanded weave nets also stopped a 47-knot torpedo, and again without damage to the net.

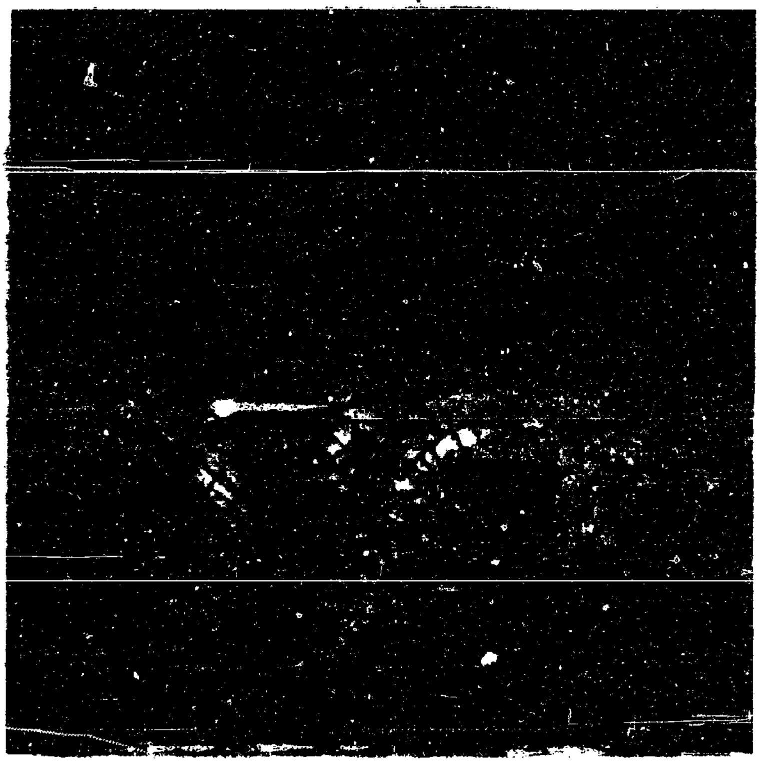


Figure 16. High speed torpedo with nose (pointed out by arrow) striking expanded weave net.

14.3.3 Conclusions

The ease with which the expanded weave net caught 47-knot torpedoes indicates that faster and heavier torpedoes can be caught in this manner with a high degree of success. With the use of $\frac{5}{16}$-inch diameter strand, torpedoes with speeds greater than 50 knots might be stopped.

Investigations should be continued on the use of slip seams to improve the shock-absorbing qualities of the net, on the use of larger mesh to reduce the total weight, and on uniform expansion of the mesh to reduce drag in the water.

The expanded weave nets developed in this investigation are believed to be eminently practical. A plan for commercial manufacture has been developed, and the contractor presents as his "unequivocal recommendation that nets of this proven design be placed in use on all cargo ships operating in torpedo-infested waters."

14.4 PROTECTION AGAINST MAGNETIC TORPEDOES

14.4.1 Procedure

On theoretical grounds, it appeared that a practical protection against magnetic torpedoes could be based on the use of electrically energized cables to produce a magnetic field at a safe distance from the ship. A torpedo entering this field would presumably fire before it reached its target.

To investigate this possibility, measurements were made of the magnetic fields produced by various types of cables at different positions around the ship and carrying different currents.[14] The experimental designs were limited by the equipment and facilities of a merchant vessel which would carry the protective device, by the speed and effective destructive range of known torpedoes, and by the sensitivity of torpedoes known or believed to be used by the enemy.

Sea trials were made with 1,000-ampere, 15-cycle alternating current at 60 volts and with direct current. The cable was installed on an EC-2 Liberty ship equipped with nets. The torpedoes traveled at 45 knots and at a depth which would allow them to pass under both the nets and the keel. They carried detonating heads which released phosphide smoke bombs at point of firing.

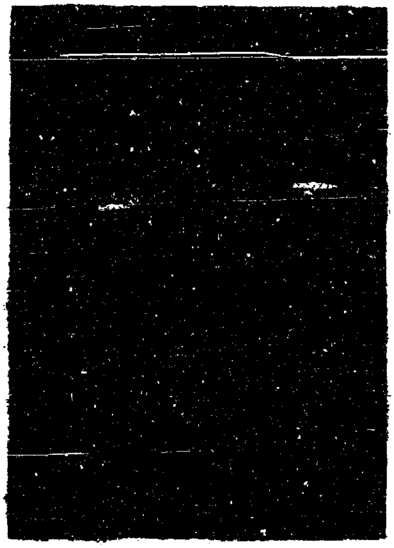


FIGURE 17. High-speed torpedo shown just after impact against expanded weave net, when it has swung the net around the Blondin as a center. A moment later, the net settled into water and the torpedo remained caught in the same mesh.

14.4.2 Results

When the cable was armed with 15-cycle alternating current, the oncoming torpedoes fired before they reached the net or fired under it.

When the cable was armed with direct current, they fired between the net and the ship or under the ship.

14.4.3 Conclusions

It was found that alternating current at 15 cycles provides a high degree of protection against the type of magnetic torpedo used in the field trials, and it is believed that lower frequencies will give at least as satisfactory performance.

Numerous alternate types of cable and power source may be used to provide the magnetic field desired. With 15-cycle current, it is recommended that the cable be 1,000,000 cir mils copper, reinforced with a steel core and surrounded with a flexi-

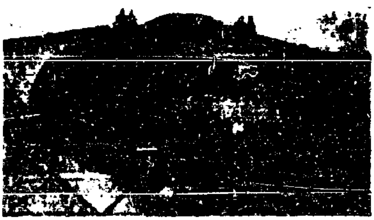


FIGURE 18. Three-compartment flotation buoy for static net protection against torpedoes.

ble, wear resistant insulation. It should be attached to the TND booms and run from bow to stern, making a complete loop around the vessel, independent of the nets. The power source should be a 20-kva, steam-driven generator to operate at 440 volts, single phase, 15 cycles per second, with an output of 45 amperes, and a transformer to step the voltage down to 60 volts, 1,000 amperes.

Intelligence reports on captured specimens of the Italian SIC head and its German counterpart, the Pi2C, indicate that these magnetic pistols are readily actuated by alternating-current fields of low frequency. The maximum sensitivity of the SIC is at 12 cycles per second, and of the Pi2C at 6.5 cycles of a sinusoidally varying field. Either a 1,000-ampere, 12-cycle current or a 250-ampere, 7.5-cycle current would provide a suitable magnetic field for protection against these torpedoes.[17]

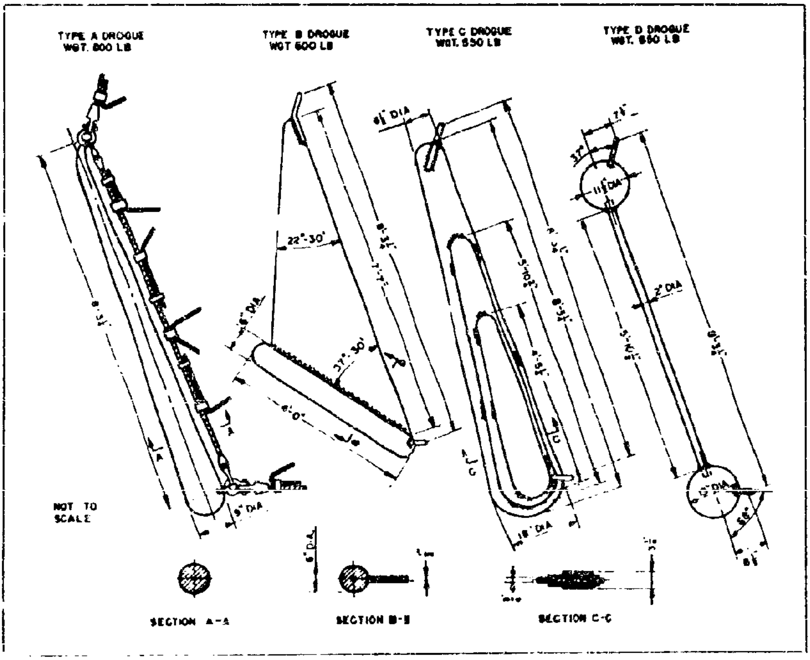


FIGURE 19. Details of trial drogues designed for antitorpedo nets.

FIGURE 20. Underwater photographs of passing small boat propeller.

14.5 PROTECTION OF MOORED VESSELS

Antitorpedo nets have long been used in harbor protection to defend moored vessels against torpedo attack. For this purpose the nets are suspended by buoys and placed around the vessels or across narrow channels.

From the results of the investigation discussed here, it appears that the improved nets, particularly the expanded weave net for protection against high-speed torpedoes, would be particularly useful in this static type of protection. Field tests with the expanded weave net showed that it is as effective when moored as it is when streamed by a moving vessel.

To improve static defense, a new flotation buoy was produced with ogive ends and three compartments which should be able to withstand machine-gun strafing (Figure 18). It provides a means of attaching the net which eliminates frictional wear on both net and buoy, and its shape provides quick response to reactions imposed on the net by torpedo impact. The new buoy can be knocked down and nested during shipment.[12]

14.6 DETECTION OF TORPEDOES

A closely allied investigation on sonar equipments designed for merchant vessels as automatic, constantly alert detecting systems was conducted simultaneously by another National Defense Research Committee division. A report on these devices, including an analysis of American and British systems, is presented elsewhere.[d]

14.7 MISCELLANEOUS NET EQUIPMENT

In addition to the major developments, the investigation yielded other devices and recommendations for improvements.

Numerous moving pictures and still photographs were taken for instruction of TND Depot personnel.

Four different types of drogue (Figure 19) were manufactured to submerge the net more satisfactorily in a seaway, and favorable trial reports were obtained on at least two.[6]

It had been noted that the Blondin roller used with the nets often failed as a result of abrasion and direct loading. In place of the small-diameter, cast-iron rollers, malleable iron rollers were substituted and gave better service. These new rollers should have been even larger in diameter, but the circumstances of the investigation did not permit this change.[5]

In order to obtain a mesh strand intersection clip which would not tear or slip at torpedo impact, a double-barreled steel sleeve was produced and swaged onto a strand intersection. It resisted slip and tear up to the breaking strength of the strand itself.[12]

[d] See *Summary Technical Report*, Division 6, Volume 14, NDRC, in press.

11.8 UNDERWATER PHOTOGRAPHY

In order to determine the exact manner in which FND nets operate and in which the mesh entangles the tail of a torpedo, consideration was given to the possibility of obtaining a series of underwater photographs.

Locations were found in southern waters where the water is about 15 to 50 feet deep with slow currents and sufficient clarity to permit underwater photography. It was planned to place three high-speed cameras in each of two underwater caissons which could be supported from a stationary bridge and maneuvered out of the way if an off-target torpedo endangered them. The cameras would be operated from the surface and would be focussed on a point about 15 feet away, covering an area approximately 10 to 15 feet square.

It was then planned that an EC-2 ship of heavy draft would travel at normal speed along a line of buoys so that her nets would pass through the area of camera focus, and that a firing device at a prescribed distance would discharge a torpedo to hit the net in the area in focus.

It soon became apparent that the acquisition of a target ship and a firing device, the construction of the camera supports, and the preparation of necessary air and surface protection would entail very considerable expense and some hazard. It became apparent, too, that because of the limited accuracy of available torpedo firing devices and because of the water turbulence in a torpedo wake, the chances of obtaining successful underwater photographs in the manner contemplated are practically nil. Accordingly, because of the difficulties, expenses, and hazards involved, this phase of the project was not carried any further.

Figure 20 shows frames selected from moving pictures made under water in a clear Florida lake with a brilliant sandy bottom. The pictures were taken of a propeller on a surface craft by means of special subsurface equipment manufactured by the Bell Telephone Laboratories.

It was suggested later that preliminary experiments be made with a model torpedo and a model moving net, reduced to a 1 to 10 scale, in clear inland waters or a suitable tank, but this plan was not approved because of the great expense of a model torpedo and moving net, and the length of time necessary to acquire the needed technique.

Chapter 15

LAND COMBAT VEHICLES

Summary

PLANS have been made for the development of a new series of combat vehicles designed to combine the best features of tanks already tested in battle with the best new features developed by collaboration of leading military, scientific, and industrial authorities. This new "Turtle" series includes lightly armored but highly mobile units suitable for air transport, medium units, and heavy units.

Mockups were prepared for the first two types in the series. One of these, investigated only in an exploratory study, is a medium tank with a weight of approximately 35 tons, a low silhouette, an all-welded hull, and a 3-inch gun. Consideration was given to various modifications, including one with twin 37-mm guns, another with four .50-caliber machine guns, a heavy assault unit carrying an 81- or 105-mm gun, and a unit specially designed for defense against low-flying planes and carrying two eight-gun pom-pom type mounts.

The second type, the light, highly mobile combat vehicle, was studied in two models: one with eight wheels to carry a 3-inch gun, the other with four wheels to carry lighter armament. Both models include all-wheel drive, a hydraulic anti-recoil system, and a new type of independent, all-wheel suspension to enable the vehicle to jump over ditches, fences, and similar obstacles. The design of these models is featured particularly by the large energy absorption of the suspension to give improved riding qualities, large recoil-absorbing capacity even with conventional type shock absorption, brake-balanced differential drive, and provision of facilities enabling the vehicle to squat. A full-scale test unit consisting of one wheel with its drive, suspension, adjacent frame members, and hydraulic jumping equipment was constructed and subjected to tests. These indicated that a full-scale vehicle incorporating the newly developed system can clear a height of 19 inches and a length of 17 feet at a speed of 30 miles per hour.

Because of inability to secure the cooperation of the Chief of the U. S. Army Ordnance Department and the automotive industry, all work on the National Defense Research Committee [NDRC] series of tanks was abandoned.

In another study, preliminary plans were prepared for vehicles, devices, and techniques for use in demolishing enemy-held public utilities systems and later in restoring them.

15.1 TURTLE[a]

15.1.1 The Problem

In April 1941, after observations on the performance of current tanks and particularly after a study of their resistance to enemy attack, it appeared to both NDRC and the Ordnance Department that improvement was necessary in the design of gun mounts, vision devices, ammunition feed systems, and in the means for operating the turrets.

Although work was undertaken on improving these tank components, as reported later in this chapter, it soon became apparent that any major improvements were limited by the over-all design of American tanks. Accordingly, a project was set up for the design, construction, and testing of one or more full-scale pilot models of a series of armored combat vehicles. These vehicles were to incorporate those characteristics found most desirable in battle, together with the most useful new components which could be developed in cooperation by military, scientific, and industrial authorities.

Later, after major tank engagements in Russia and the Libyan desert had disclosed many of the actual advantages and weaknesses of our tanks and other armored vehicles in modern battle, this broad research and development program was given additional, though temporary impetus by a formal directive from the Chief of Army Ordnance.

In general, the specifications called for combat vehicles which would have maximum superiority over enemy vehicles and maximum protection against enemy antitank techniques. They included (1) a high degree of mobility, (2) a stable firing platform, (3) high firing accuracy while in motion, (4) a low silhouette and silent operation for security and surprise, (5) complete integration of functions of each type to permit either independent or group operation, and (6) a

[a] Projects OD-30 and OD-27.

high degree of mechanical reliability. It was agreed that each type in the series should lend itself to mass production by incorporating as far as possible those components which were already available, and that the synthesis of these components into a complete, efficient vehicle should not require prolonged development or mark any departure from proved engineering principles.

15.1.2 IVI Tank[b]

PROCEDURE

An analysis of medium tank design led to a number of fundamentals which were considered desirable for attainment of the major objectives.[c] These were:

1. Ninety per cent of all tanks should have the same chassis, making mass production possible.
2. Ninety per cent of all tanks should have the same standard, adequate armor for their vital parts and for their crews.
3. Ninety per cent of all tanks should have weapons capable of both offensive and defensive action against other tanks, antitank guns, pill-boxes, infantry, and low-flying aircraft.

[b] Project OD-30.

[c] This investigation was conducted by the United Shoe Machinery Corporation, Boston, Mass.

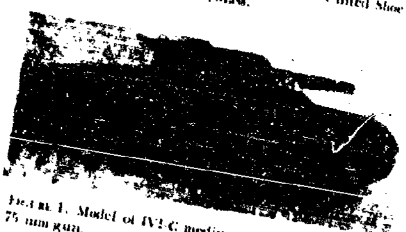


FIGURE 1. Model of IVI-C medium tank equipped with 75-mm gun.

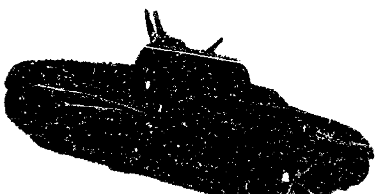


FIGURE 2. Model of IVI-C medium tank equipped with two 37-mm guns.

4. All tanks should have interchangeable and replaceable armament which could be applied without redesigning the tanks or making major changes either on the production line or in the field.
5. Ninety per cent of all tanks should carry weapons with a rate of fire at least equal to that of a hand-operated, full-crew gun of equal caliber—a requirement which can be met only by automatic weapons.
6. Weight should be reduced to a minimum to give high speed.

The turret in the tanks existing at the time of this study was deemed incapable of providing the protection expected of it, and its added weight did not seem to be justifiable. The small space within the turret prohibited full use of automatic weapons. Turret designs increased the complexity of tank production.

Therefore, it was felt that the turret should be completely redesigned and arranged to incorporate such guns as the 75-mm gun with a rate of fire of 30 to 45 rounds per minute, the M-4 37-mm gun with a rate of 120 rounds per minute, or the .50-caliber machine gun with automatically operated remote controls. The 75-mm gun was then being redesigned, the 37-mm gun was in production for the P-39 Airacobra fighter plane, and the .50-caliber machine gun was ready to go into production for the Army Air Forces.

With such guns as these, it was believed that the chassis and transportation portion of the tank could be mass-produced, and that the armament could be installed without difficulty to give any desired fire power combination.

Mock-ups were prepared in this exploratory study to show the possibilities of a basic chassis and protective armor, low silhouette, and interchangeable and readily replaceable automatic fire power.

RESULTS

Design IVI-C. One concept of the new medium tank design represents a more or less conventional

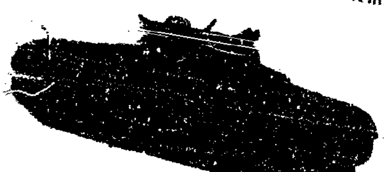


FIGURE 3. Model of IVI-C medium tank equipped with four .50-caliber machine guns.

organization, drive, crew, and armament. The crew is reduced to four men, a driver and a radio operator forward of the turret, a commander and a gunner in the turret. This tank would weigh 30 to 35 tons and would be 7 feet high, 9 feet 4 inches wide, and 18 feet 7 inches long.

The main turret armament consists of one 75-mm cannon, two 37-mm cannons, or four .50-caliber machine guns, all of them replaceable and interchangeable (Figures 4 to 6). These guns are capable of 360-degree rotation in azimuth, and elevations of −10 to +45 degrees for the 75-mm, and −10 to +85 degrees for the 37-mm and the .50-caliber. In addition, the driver has two .30-caliber machine guns capable of −10 to +30 degrees elevation, and the commander, located in the turret, has one forward .30-caliber machine gun for fire against ground troops and low-flying aircraft and one rear .50-caliber machine gun.

The armor is from 3 to 3½ inches over all vulnerable surfaces and can continue down over the treads to the road clearance (16 inches). The low surface angles and the small frontal and side areas exposed to fire should offer considerable protection against enemy fire. In this particular design, the crew are well below the main body lines of the tank and are well protected.

Automatic feed is planned for all armament to give maximum rate of fire. Accuracy of fire would be improved by stabilization of the gun in both azimuth and elevation, and possibly by stabilization in elevation and azimuth of both gun and driver through some limited throw such as 10 degrees.

The gunner has 360-degree azimuth vision afforded by the turret rotation. His elevation vision depends upon the main armament used. The commander has 360-degree azimuth vision independent of the turret and −10-degree to +85-degree elevation vision. The driver has −10- to +30-degree elevation and no azimuth vision.

By use of a 600-hp motor and by the reduction of track friction, a speed of 30 to 35 miles per hour is believed possible. Air cleaning and air-conditioning equipment could be included for certain services in order to maintain the efficiency of the crew and the life of the mechanical parts.

The tank would be designed for mass production using large unit pieces rather than assemblies which would require accurate fits and prolonged assembling operations.

In contrast to the M-8 medium tank, the IVI-C has a low, compact design with minimum crew requirements and sufficient volume to carry necessary auxiliary equipment and gasoline for a greater operating range. Its silhouette is 3 feet lower. It would be capable of resisting heavy caliber fire because of its heavier armor and low deflection angles. The total weight of the IVI-C, however, would be greater be-

FIGURE 5. Model of IVI-D medium tank equipped with two 37-mm guns.

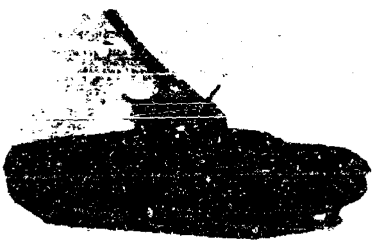


FIGURE 4. Model of IVI-D medium tank equipped with 75-mm gun.

FIGURE 6. Model of IVI-D medium tank equipped with four .50-caliber machine guns.

cause of its increased armor thickness and the use of armor over the treads.

Design IVI-D. This design is the same as that for the IVI-C series except that the turret enables the gunner to move with the gun both in azimuth and in elevation (Figures 4 to 6). Such a modification provides the most direct solution of the problem of high-angle vision, for the vision device is a straight-through protectoscope similar to that used in the M-3 medium tank. The field of such a protectoscope could be considerably greater than for the type in use, since it need not be contained in a small drum.

The elevation for this type of gun mounting can be increased to +85 degrees without increasing the over-all height of the tank. The design also allows the use of low surface angles on the sides of the turret.

Certain disadvantages, however, are apparent. This type of turret requires more machining, difficult shielding is required to protect adjoining sliding surfaces from shellfire, and more armor is needed in the areas of the rotating portion which are vulnerable to shellfire throughout the entire elevation of the gun.

Special Designs. Figures 7 and 8 show a slightly different arrangement of operator, motor, and guns. Use of this modification would depend on a careful consideration of cubage, operator comfort, gun operation, etc.

The mock-up of an assault unit is shown in Figure 9. This is a shielded, heavy-caliber mount for an 81- or possibly a 105-mm gun, and would have the major purpose of assaulting enemy strongholds, such as pillboxes and fixed fortifications. In addition it would carry a gun crew and selected shock troops to aid in holding positions taken.

An antiaircraft unit, illustrated in Figure 10, is designed for defense against low-flying aircraft. With two eight-gun pom-pom type mounts, it would direct heavy fire against hedge-hopping planes attempting to bomb or strafe troops, and would have sufficient speed and mobility to keep up with the advance ground forces.[4]

FIGURE 7. External view of model of modified IVI medium tank.

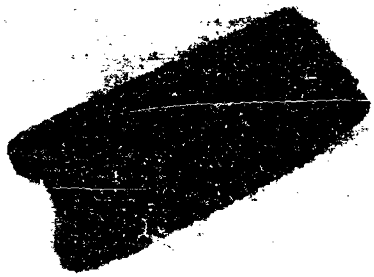


FIGURE 8. Internal view of model of modified IVI medium tank.

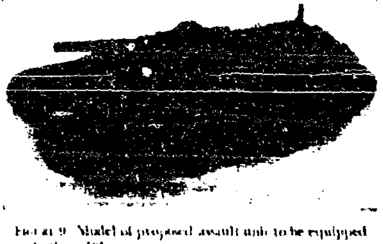


FIGURE 9. Model of proposed assault unit to be equipped with 81- or 105-mm gun.

FIGURE 10. Model of IVI antiaircraft unit equipped with two eight-gun, pom-pom type mounts.

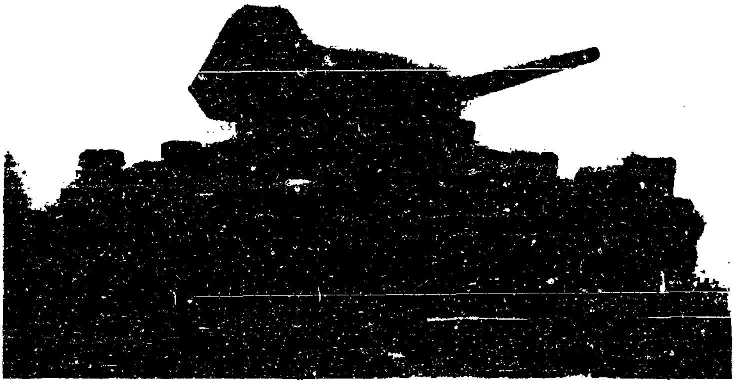


FIGURE 11. Model of eight-wheel light combat vehicle.

18.13 Baker Tank[d]

PROCEDURE

In the development of light units to be included in the proposed Turtle series, it appeared that the program could be most profitably started by the design for a new type of combat vehicle—a self-propelled assault gun to take a leading role against tank, antitank, and artillery gun emplacements. It would combine many of the best features of the long-range reconnaissance car and the tank destroyer, representing a transition in offensive weapons.

As outlined by NDRC, the first step in this project was the selection of a gun which would be satisfactory to the Ordnance Department. Once the major armament was approved, design work could begin on the most efficient chassis to carry it, the best method of applying traction, the best armor to protect it, and the best tactical aids which could be taken from current armored vehicle models, developed by other NDRC projects already under way, or designed in new NDRC projects to be set up for that purpose.

Armament. Immediate consideration was given to both high-velocity and hyper-velocity guns which were either available or undergoing final development, together with special projectiles developed for some of them.

Among the *high-velocity* guns studied were the twin 37-mm guns used in the Maxson turret, the 57-mm gun for light tanks, the 75-mm gun with an increased muzzle velocity of 2,600 fps, the 88-mm gun for 25-ton tanks, the 90-mm antiaircraft gun, and the British 3-inch gun. Of these, the 3-inch gun appeared to be the most useful. It weighs only 2,650 pounds with its mount, in contrast to 5,000 for the 90-mm gun, and, with a muzzle velocity of 3,000 feet per second, will penetrate 90-plate steel at 1,600 yards. This gun has a useful destructive range of 3,000 yards and a maximum range of 8,000 yards; it can fire 2,500 rounds at 2,650 fps and 500 at 3,000 fps.

Consideration was likewise given to *hyper-velocity* guns, which were developed to minimize erosion, particularly at the breech end of the tube where it reduces the life of the gun, and to give a higher muzzle velocity, a flatter projectile trajectory, a shorter time in flight, and a higher penetration of armor. Of all the hyper-velocity devices available or under development,[5-7] the best for the purpose appeared to be the Probert gun, at the time being proved in England, which develops muzzle velocities of 3,300 to 3,500 fps; the Janacek choke and the Littlejohn-Janacek conversion, which fit over the muzzle of a standard gun and adapt it to the conical bore principle; and the modified Kern and Gerlich conical bore guns which were then being studied by other divi-

d Project OD-60

FIGURE 12. Model of four-wheel light combat vehicle, with turret removed.

sions of NDRC. At the same time, attention was given to the Arrowhead type projectiles being developed by the British and the U. S. Army, which develop a muzzle velocity of more than 4,200 fps, and to deformable projectiles under consideration by the British and the U. S. Navy. Although interest was constantly maintained in all these types, none appeared to be sufficiently developed or satisfactory for incorporation in the proposed new combat vehicle.

Accordingly, the preliminary designs were undertaken for a combat vehicle to carry the British 3-inch gun as its major armament.

Chassis. As a result of improvements in armor-piercing weapons, it seemed desirable to design the new vehicle as a lightly armored but highly mobile tank which would offer relatively little protection against

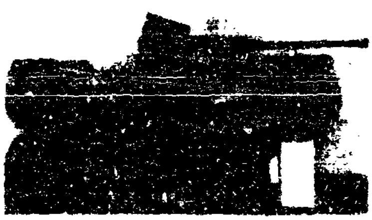


FIGURE 13. Extent of suspension travel shown in model of four-wheel light combat vehicle.

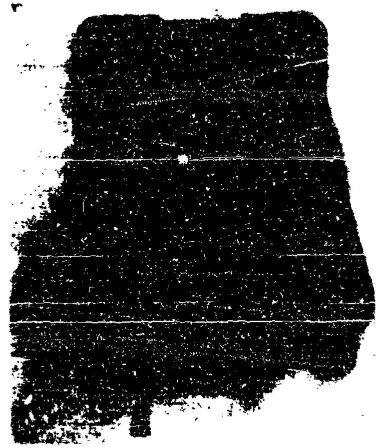


FIGURE 14. Interior layout of model of four-wheel light combat vehicle.

direct artillery fire but which would be exceedingly difficult to hit. To provide this mobility over any kind of terrain and to reduce maintenance requirements, it was decided to use wheels instead of tracks, with all wheels driven, and to make provisions for air transport.[e]

Early in the program, an investigation was conducted on the possibilities of incorporating some means to enable the vehicle to negotiate ditches, trenches, low fences, and similar obstacles by jump-

[e] This investigation was conducted by the Baker Manufacturing Co., Evansville, Wis., under OSRD contract OEMsr-521.

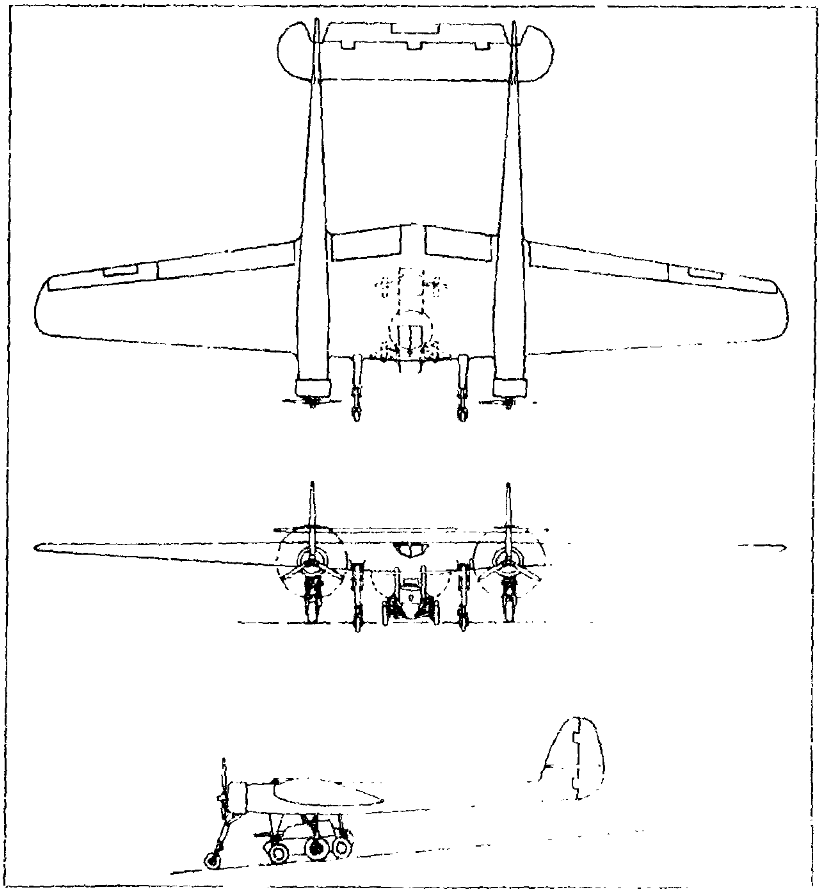


Figure 15. Plan, front and side views of light combat vehicle as attached for air transportation.

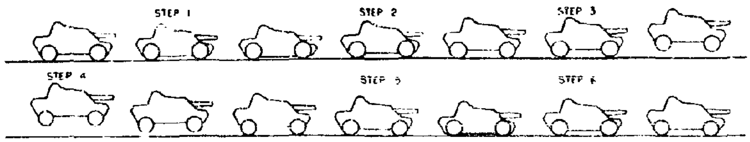


FIGURE 16. Jumping cycle: (1) chassis squats, (2) chassis accelerated upward, (3) wheels accelerated upward, (4) vehicle in air, (5) chassis decelerated upward, and (6) chassis rises to normal road clearance.

ing over them. It was determined[3] that the vehicle could be made to jump by a sudden downward push of the running gear, and that the height and length of the jump would be determined by the length of the running gear downstroke, the magnitude of the downward force and the forward velocity of the vehicle at the time of the jump. The apparatus required for such a performance would consist of hydraulic or pneumatic cylinders, together with appropriate valves, an accumulator, and a pump driven from an engine. A rough plan was accordingly developed for a mechanism to incorporate these units, a jumping technique was outlined, and a test unit was constructed for testing and analysis.

In considering the possibilities of a jumping vehicle and also in reviewing existing wheeled vehicle designs, it was concluded that both the permissible travel of the spring suspension and the vehicle width should be as large as possible. The general design of the chassis therefore included maximum suspension travel in order to increase the resistance to shocks, including gun recoil reaction, to permit jumping, and to permit setting the bottom of the vehicle on the ground quickly to reduce recoil reaction movement

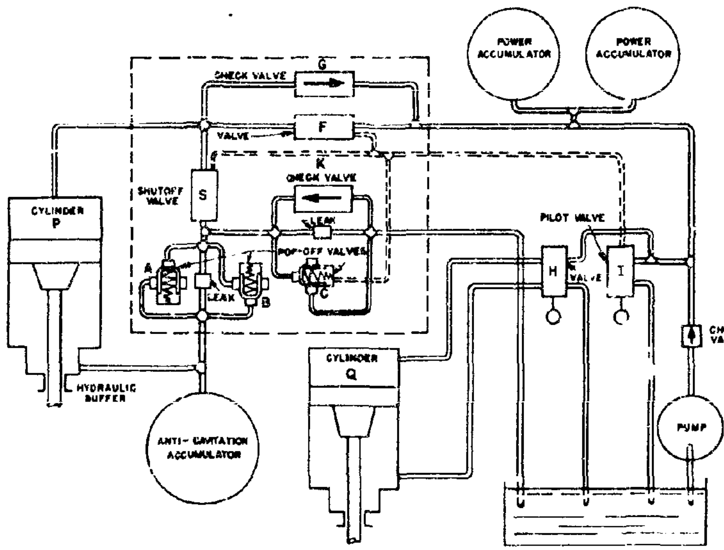


FIGURE 17. Diagram of proposed hydraulic jumping system.

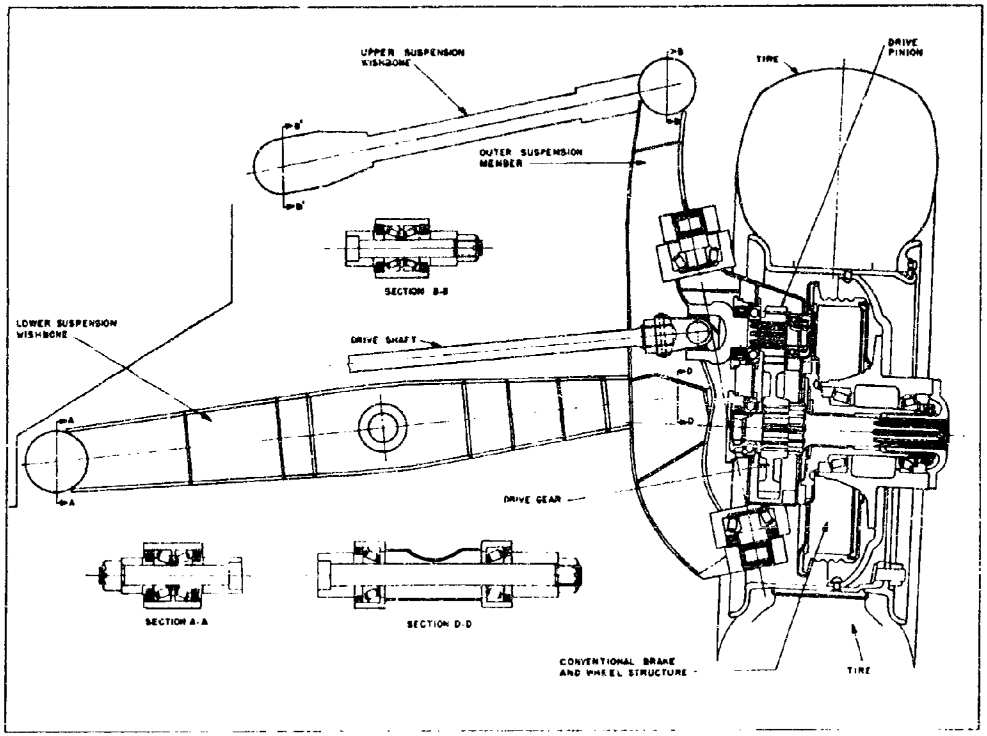


FIGURE 18. Construction of wheel drive and connections to vehicle frame.

and to lower the silhouette. The width was made as great as possible to improve absorption of gun recoil, to permit larger suspension, and to make possible the use of a lower spring rate, giving a better ride for a given side roll in turning.

Considerable improvement in traction was expected by connecting an extra hydraulic system into the conventional hydraulic brake control in order to give automatic balancing of the drive differential.

An investigation was also conducted on methods of minimizing the effects of gun recoil. Gyroscopic devices were studied as possible anti-recoil systems but discarded because of their undue size and complicated mechanisms. A system transmitting the torque through the wheels was considered preferable, with the transmission accomplished most conveniently by means of a hydraulic cylinder, and a workable design was investigated.

Development studies and recommendations on other devices and improvements, including those concerned with reduction of tank noise, improvement of vision, gun mounts, communications, fire control, detection, navigation, camouflage, and various attack aids were conducted in cooperation with those Office of Scientific Research and Development and NDRC divisions concerned.

Results

Figure 11 shows a mock-up of the proposed eight-wheel vehicle, with a wheel base of 189 inches and a width of 121 inches. Its total weight, including two engines and a 3-inch or similar gun, is estimated to be less than 20,000 pounds. Figure 12 shows the chassis of a four-wheeled version to carry a smaller gun of about 40-mm caliber, with a wheel base of 137 inches, a width of 121 inches, and an estimated weight of less than 10,000 pounds.[17]

Both vehicles include all-wheel, brake-balanced drive, and the new type of independent, all-wheel suspension. Figure 13 shows one wheel in its highest position and one wheel in its lowest to illustrate the extent of the suspension travel. The interior layout is indicated in Figure 14, with facilities permitting the driver to steer in either direction from the same steering wheel.

Air Transport. Figure 15 shows the features of a scheme for transporting the vehicle by air in such a way that it can be quickly unloaded by releasing on touching or approaching the ground. It is believed that two 700-horsepower motors, a wing span of 124 feet, and an over-all length of 66.5 feet would be required. Maximum speed would be 145 mph, cruising speed 130 mph, and landing speed 50 mph. This plan would not be adapted for long-haul or high-speed air travel because of the low landing speed required and the large aerodynamic drag of the exposed vehicle.

Jumping System. Theoretical studies and preliminary tests on a device which would enable the vehicle to jump over obstacles led to the design of hydraulic

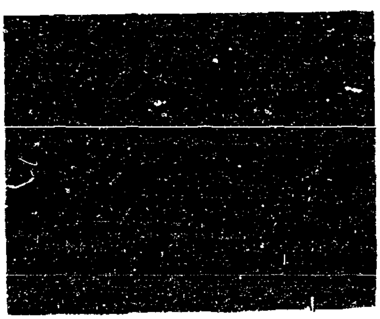


Figure 20. Experimental wheel unit in normal position.

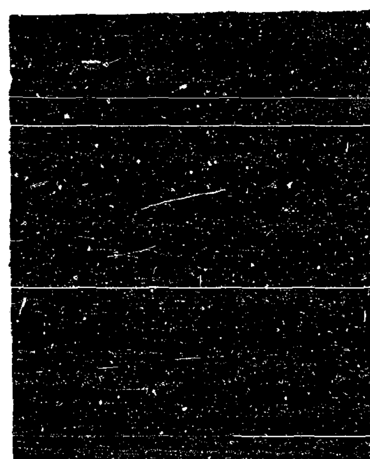


Figure 21. Experimental wheel unit, chassis raised.

equipment which would operate in a six-step jumping cycle (*Figure 16*):[13]

1. A relatively slow squatting of the chassis to the minimum road clearance permitted by the terrain.
2. A rapid upward acceleration of the chassis with respect to the wheels by means of hydraulic cylinders.
3. A rapid acceleration of the wheels up to the velocity of the chassis, accomplished by a throttling buffer at the end of the hydraulic cylinder.
4. A flight through the air during which the vehicle would hurtle the obstacle.
5. An upward deceleration of the chassis, during which the kinetic energy of vertical velocity of the chassis would be absorbed.
6. A relatively slow raising of the chassis up to normal road clearance.

During step 4, the wheels could be raised and the net height of the jump would be increased, but the added operations of raising and then lowering the wheels would require the use of twice the oil expended in step 3 and would necessitate more complicated apparatus.

In the proposed jumping system as shown in Figure 17, the energy for jumping is supplied to an oil pump and is stored by compressed air in power accumulators from which it is transmitted hydraulically to the jumping cylinders.[15] In order to investigate the actual operation of such a system, a full-scale wheel unit with drive, suspension, and adjacent frame members was constructed as shown in Figure 18, with the hydraulic cylinder used for jumping and for absorbing shocks, as shown in Figure 19. Oil enters the cylinder on the top trunnion axis, making a right-angled turn just at the cylinder entrance. Oil leaving the lower side of the cylinder flows through the annular space surrounding the cylinder and out along the trunnion axis. The suspension and cushions are provided hydraulically by means of piston extensions which restrict the flow of exit oil near the ends of the stroke.

Figure 20 shows the experimental unit, Figure 21

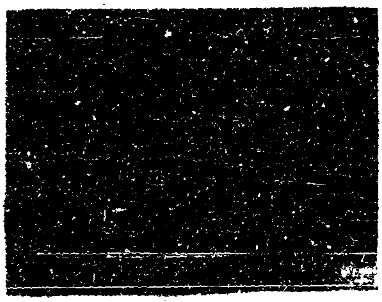


FIGURE 22. Experimental wheel unit, chassis lowered.

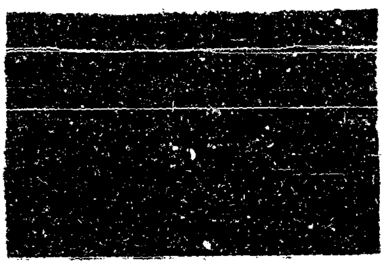


FIGURE 23. Merry-go-round setup for experimental wheel unit tests.

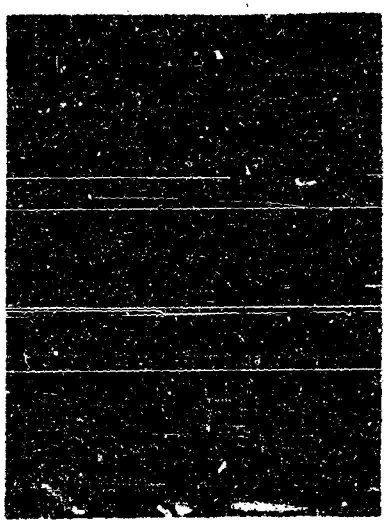


FIGURE 24. Experimental wheel unit clearing height of 19 inches.

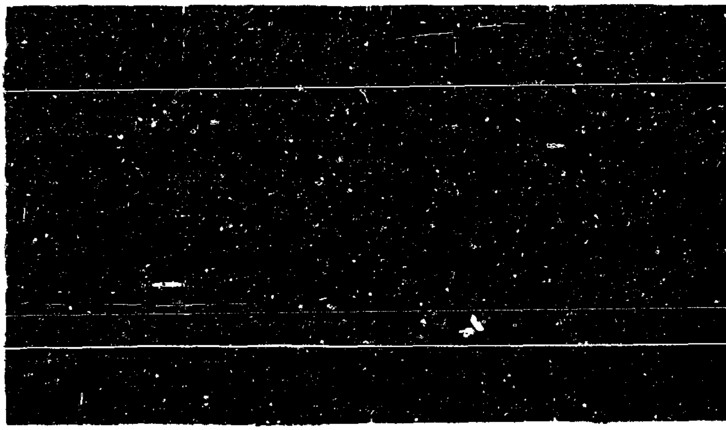


FIGURE 25. Sequence of views showing experimental wheel unit during jumping (left to right).

illustrates the highest suspension position, and Figure 22 shows the lowest position.

This unit was then mounted on a large radius arm to permit merry-go-round testing, as shown in Figure 23. The tests showed that the basis of the design is fundamentally sound. In one jump, as illustrated in Figure 24, the wheel cleared a height slightly more than 49 inches; for a vehicle with a 137-inch wheel base traveling at 40 mph, this height corresponds to a jumping distance of 47 feet.

A series of moving picture views of the suspension during jumping is shown in Figure 25.[10]

Anti Recoil System. The equipment required for a possible hydraulic anti recoil system for the Turtle is illustrated in Figure 26.[11] The source of pressure is connected to both ends of each cylinder through valves sensitive to vertical accelerations. The valves connected to the lower ends of the cylinders admit pressure proportional to acceleration into the lower halves of them when the valves are accelerated downward. An upward force is thereby produced similar to that which would be exerted by an added mass. The action of the valves connected to the upper ends during upward acceleration is similar. Fixed orifices are located between the acceleration controlled valves and the cylinders. These orifices add to the pressure in the end of each cylinder from which oil is being forced out and subtract from the pressure in the end into which oil is being admitted, producing a force which is a function of the relative velocity between the chassis and the wheels.

One possible type of acceleration-controlled valve is shown in Figure 27. When the pressure in the inlet pipe is too low, the plunger is pushed to the left, either increasing the opening of an orifice from the source of pressure or decreasing the opening of an orifice leading to the sump, thereby increasing the pressure in the inlet pipe. When the pressure is too high, the action is similar except that the movement takes place in the opposite direction. Thus the pressure in the inlet pipe is maintained approximately proportional to the acceleration. When downward accelerations occur, the mass opens wide the outlet valve of chamber C and the pressure in C falls, causing the valve between the inlet pipe and the sump to open completely.

During recoil, the acceleration controlled valve can operate without a source of pressure and acts as an added mass, while during the continued rocking in the same direction after recoil, the valve cannot operate and the added mass disappears.

A valve such as the one in Figure 28 is required at each end of each cylinder. This is similar to the one in Figure 27 except that the oil flowing into chamber

C comes from a space between the throttling valve and a pop-off valve. The pop-off valve maintains an approximately constant pressure while oil is flowing through it.

Miscellaneous. Many of the devices and developments studied by various divisions of NDRC are believed to be more or less applicable to these and other vehicles. Studies on the reduction of tank noise, centrifugal self-cleaning air cleaners, gun mounts, viewing devices, protectoscopes, gunner's seats, bouncing characteristics, and control of fog, sleet, and rain are reported elsewhere in this volume. The reports on ordnance improvements, fire control, automatic feed, improved armor, tank rockets, special hydraulic fluids, flame throwers, special communications systems, mine detectors, odographs, and the use of radar, infrared, and ultraviolet devices on tanks—all originally contemplated for the vehicles described above—are included in the summary reports of other divisions.

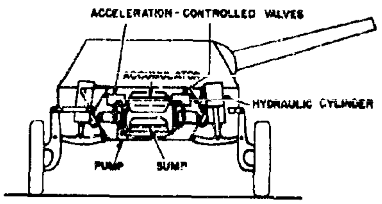


FIGURE 26. Diagram of proposed hydraulic anti-recoil system.

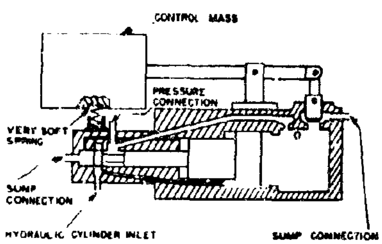


FIGURE 27. Diagram of acceleration-controlled valve.

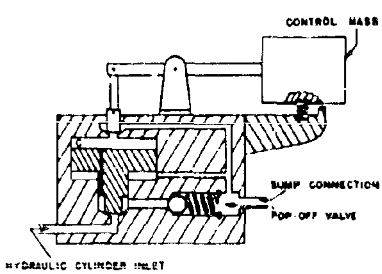


FIGURE 28. Diagram of modified acceleration-controlled valve.

CONCLUSIONS

To a large extent, the directive for this project was not fulfilled, for no complete pilot model was constructed and subjected to test. Nevertheless, the design and the principles developed for combat vehicles are believed to be noteworthy and warrant investigation on full-scale models in field trials.

15.2 DEMOLITION VEHICLE[f]

In the autumn of 1941, Division 12 of NDRC gave some consideration to the development of techniques, devices, and a necessary vehicle to be used in the demolition of enemy public utility facilities. It was suggested that this equipment might be used by highly trained specialists to destroy such services as power, light, heat, telephone, telegraph, radio, water, and sewage disposal systems in enemy cities.

This program was formally requested by the U. S. Army in September 1941 with a directive from the Executive Officer, Corps of Engineers, requesting recommendations of techniques and equipment to prevent enemy operation of such services as power, water, and communications. At the same time, the request called for the development of restoration techniques which could be applied by troops upon occupying enemy territory.

After preliminary plans had been outlined, the project was terminated by request of NDRC on the grounds that any techniques or devices developed in this study might imperil public utility facilities in this country and increase the dangers of sabotage.[g]

[f] Project CE-20.

[g] Secret letter from Frank B. Jewett, NDRC, to General G. M. Barnes, War Department Liaison Officer, NDRC, Washington, D.C., Dec. 8, 1941.

Chapter 16

LAND VEHICLE COMPONENTS[a]

16.1 TANK COMPONENTS

Summary

An urgent development program undertaken at the request of the U. S. Army Ordnance Department in April 1941 resulted in the design of new gun mounts, viewing devices, protectoscopes, and other tank components, and a self-clearing centrifugal air cleaner for use on tanks and other motor vehicles. None of these items was put into production.

16.1.1 The Problem

Battle reports from Europe and Africa before the United States entered World War II indicated that American tanks suffered from such defects as poor visibility, vulnerability to small arms fire by lead splash, poor functional posture for the gunner, and restricted elevation of gun mounts.

At the request of the U. S. Army Ordnance Department and the National Defense Research Committee [NDRC], an urgent development program was undertaken in April 1941 to obtain new gun mounts, viewing devices, protectoscopes, and other tank components.[b] The program was to be directed primarily toward devices to be used on the experimental T-7 light tank, but also concerned the M-4 medium tank.

Soon after the introduction of motor vehicles to desert warfare, a drastic increase in failure reports marked the urgent need for a self-cleaning device to clean the air intakes of tank and truck engines. The oil-filter type of cleaner had not proved satisfactory, requiring a thorough cleaning itself after a few hours of exposure to desert dust. Tanks, trucks, and even aircraft exposed to this atmosphere were failing in such numbers that the Allied desert military campaign was gravely affected. So alarming was the situation that one military observer urged the Chief of Army Ordnance and Division 12 of NDRC, "Design a proper air cleaner, and then design a tank around it!"

16.1.2 Gun Mounts

In order to increase protection for tanks against aircraft attack, new gun mounts were required for the turrets of light and medium tanks. In the specifications set up and approved by representatives of the U. S. Army Ordnance Department, these mounts should make it possible to cover elevations up to 80 or 90 degrees. They should be mechanically simple, easy to machine, statically balanced, and interchangeable with other mounts. They must have a minimum of exposed surfaces, no pockets or re-entrant angles, a minimum spatter lap of 2 inches, and means to catch spatter that does get through, deflectors in line of probable fire, and sufficient clearance to avoid sticking of the rotor.

Combination High-Angle Mount and Protectoscope

The original request initiating work on tank problems involved redesigning a combination 37-mm, .30-caliber gun mount to permit greater gun elevation (up to 80 or 90 degrees), as well as relocating and redesigning the associated protectoscope. The new

Figure 1. Mock-up of high angle mount with gun fully elevated.

[a] Project OD-50.

[b] This investigation was undertaken by the United Shoe Machinery Corporation, Boston, Mass., under contract NDCrc-204 and OSRD contract OEMsr-112.

design was originally intended for the M-4 medium tank, but later was considered for the T-7 light tank turret.

Figure 1 shows the features of the first design. The wall of the front plate around the gun opening is built up with flanges to aid in protecting the rotor from side fire and lead splash. At full gun elevation, two shields, as shown in Figure 2, attached to the gun rotor protect the rotor by overlapping the flanged side walls. The shield is divided into two parts, a fixed part attached directly to the gun rotor and a movable part hinged to the fixed part. At low elevations this hinged shield cams outwardly on a fixed member to prevent interference with the turret shell and basket.

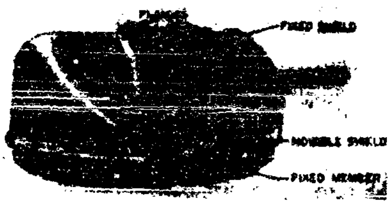


FIGURE 2. Mock-up of high-angle mount with gun lowered.

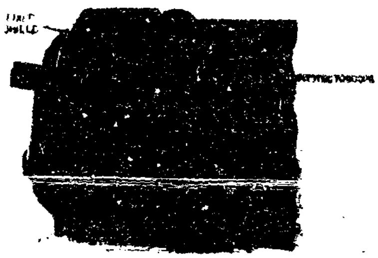


FIGURE 3. Mock-up of modified high-angle mount with single fixed shield.

FIGURE 4. Outside view of mock-up of low-angle mount.

With this design, the guns can fire at an angle of 85 degrees.

In order to provide better protection to the rotor, smoother contour, and fewer pockets, the structure was changed and a redesigned recoil mechanism was placed completely inside the rotor (Figure 3). In this plan, the rotor diameter is increased and the hinged shields replaced by a single fixed shield. This design gives good protection only at the most commonly used firing elevations.

The redesigned protectoscope is described below.

Combination Low-Angle Mount and Protectoscope

In designing the high-angle gun mount, it was found quite difficult to obtain satisfactory protection for the gun rotor over the wide range of gun elevations, and a low-angle mount was developed to give elevations between −10 and +25 degrees. This model (Figures 4 and 5) provides complete protection of the rotor from machine gun fire by the use of a shield fixed to the rotor. In order that the shield may clear the turret shell and basket, the rotor diameter is increased and the front plate is completely redesigned. The new recoil mechanism, completely housed within the rotor, is incorporated.

Adequate vision is made possible by means of a protectoscope with a rotatable upper mirror. A mirror rotor and mirror magazine are connected to the

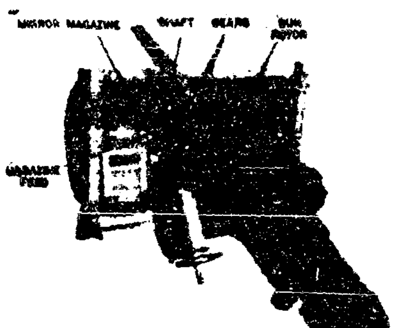


FIGURE 5. Inside view of mock-up of low-angle mount.

gun rotor by means of links, a shaft, and a train of gears, and move in proper angular relation to the gun. Without moving his head, the operator can aim the gun through a special sighting telescope in conjunction with the protectoscope at any elevation within its range. Upper mirrors are replaceable through a slot from a magazine (see the description of M-4 protectoscope below). If the mirror rotor or magazine should be damaged, a spare indirect vision device can be slipped into place. The gunner is protected from lead spatter by lap joints, spatter traps, and safety glass.

REAR TURRET MACHINE GUN MOUNT AND PROTECTOSCOPE

In addition to the combination mounts, a request was also made for a mount to carry a single .30-caliber machine gun and protectoscope in the rear of the T-7 light tank turret. Since the gun was to provide protection against aircraft, a high elevation range was specified.

The mount as designed to meet these requirements consists of a rearward-pointing, .30-caliber machine gun capable of pivoting on both axes and with an elevation range of −10 to +85 degrees (Figures 6 and 7). The companion protectoscope is mounted on the gun trunnion and moves with it. A special cam arrangement between the upper and lower mirrors gives them different angular movements which permit the gunner to sight through the entire elevation range with a minimum of head movement. Azimuth sighting is limited to 50 degrees by the width of the mirrors.

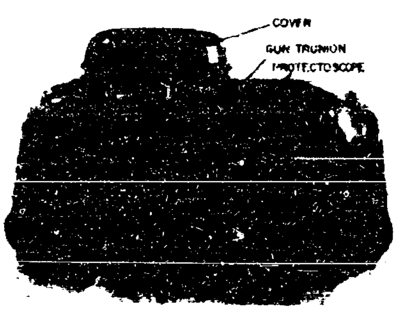


FIGURE 6. Outside view of model of rear turret machine gun mount.

MULTIPLE MACHINE GUN MOUNT

At the request of the Ordnance Department, a study was also started on the design of a multiple .50-caliber machine gun mount with an elevation range of −10 to +85 degrees for the M-4 medium tank. Layout and design drawings were completed but construction of a model stopped upon abandonment of the project by the Army.

16.1.5 Panoramic Observation Devices

A need was expressed by Ordnance Department representatives for devices which would make possible 360-degree vision for panoramic observation from tank turrets. Three different designs were prepared.

DIRECT VISION DEVICE

This simplest solution for application to the T-7 light tank turret provides a crank, chain drive, and sprockets to rotate screws which in turn can raise or lower the turret cover (see Figures 6 and 7). When the cover is raised, the gunner can make his observations through a 360-degree slot.

HEXAGONAL LOW-ANGLE VIEWER

A more complex and safer device was designed for use on either the T-7 light tank or the M-4 medium tank turret (Figure 8). The main rubber-lined body

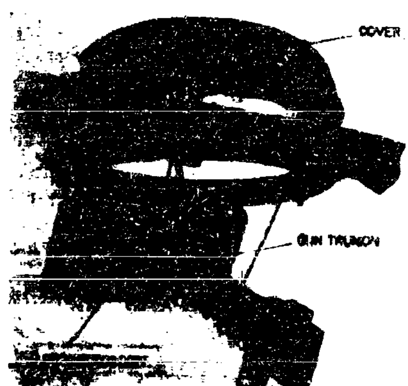


FIGURE 7. Inside view of model of rear turret machine gun mount.

has six slots placed 60 degrees apart in the plane view. In each slot is a replaceable unit periscope consisting of an upper mirror and a lower sheet metal mirror. The periscopes are replaceable from the inside. Since the six individual fields overlap, the observer can see the full field in all directions by simply turning his head. He is protected from lead splatter by special "buckets" and safety glass. The device has a very low silhouette above the turret roof and is designed for bullet deflection.

Adjustable High Angle Viewer

A further improvement on the low-angle device was designed to enable the observer to vary his field of vision in elevation from −10 to +70 degrees (Figure 9). Here the upper mirrors are cam-operated to give the desired angle. Other features of construction are similar to those of the low-angle viewer.

16.1.4 Protectoscope

The original specifications for a new tank turret protectoscope, as set up and approved by representatives of the U. S. Army Ordnance Department and NDRC, called for a small, simple, wide-angle viewing device which would give the operator maximum protection while using it or while replacing any of its exposed parts which might be damaged by gunfire.

Its horizontal field of vision should be 25 degrees on each side of center, or a total of 50 degrees, its vertical field 11 degrees, and it should be able to cover an elevation of −15 to +90 degrees or at least to the limits of the gun elevation. Where possible, plane mirrors should be used.

In addition, the new protectoscope must contain a sighting telescope on one side and provide means for coordinating with the gun. Provisions must be made for enabling the operator to steady his head while sighting, to keep his eye a fixed distance from the telescope, and, if possible, to get emergency vision in case the optical system fails. There must be a minimum of exposed surface, with no moving parts of the optical system in line of fire, a minimum spatter lap of 2 inches and means to catch spatter that does get through, and sufficient clearance to avoid sticking when pitted. The dimensions called for a maximum diameter of 12 inches, preferably 5, and an over-all scope width of 8 inches. If possible, the protectoscope should be interchangeable in all mounts.

Essentially, the requirements demanded an exceedingly close-coupled periscope with the smallest number of exposed parts and with facilities for the operator to replace any of these exposed parts without exposing himself to enemy fire.

M-1 Protectoscope

The device as developed originally for the M-4 medium tank and later for the T-7 light tank is designed as a periscope using a rotatable upper mirror (Figure 10). This mirror is connected by gears, links, and shafts (Figure 11) to the gun rotor and turns in such relation to the gun that the gunner always sees the field at which the gun is aimed.

If the mirror is shot away, it is replaced with a new one taken from a mirror box and slipped into place by means of a magazine feed (Figure 12). The magazine itself is mounted on the mirror rotor and feeds new mirrors through a protected slot in the rotor. One stroke of the handle moves the mirror halfway out, where a small stop drops in behind and holds the mirror. A second stroke of the handle then moves the mirror the rest of the way out and into grooves in the main rotor (Figure 13). After the mirror has been ejected from the magazine, a flat spring pushes a new

Figure 8. Hexagonal low-angle viewer.

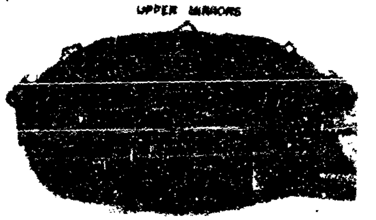


Figure 9. Adjustable high-angle viewer.

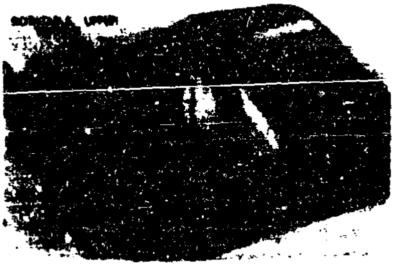


Figure 10. Rotatable upper mirror for protectoscope.

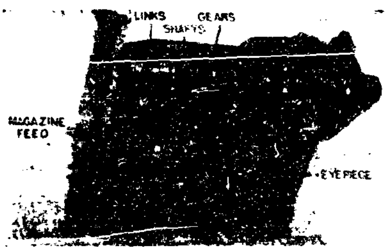


Figure 11. Inside view of protectoscope.

mirror into position in the magazine, ready to be fed through the slot.

A headrest is provided so that the operator can steady his head at a fixed distance while sighting.

A model of this device was constructed of cast-armor steel and tested against .30-caliber Army rifle and .50-caliber machine gun fire. The protectoscope satisfactorily sustained hits from both ball type and armor-piercing bullets except when they struck directly on the small rotors carrying the mirror and mirror magazine. The magazine principle of mirror ejection, however, proved successful. No lead splash penetrated to the operator's position.

16.1.5 Machine Gun Accessories

In order to improve the firing of the .50 caliber Browning machine gun manufactured by Colt for the M-4 medium tank, a study was conducted of an electrically powered assist-feed to lift belts of cartridges from the rounds container and deliver them to the gun as fast as needed. At the request of representatives of the Ordnance Department, the device was to fit the standard Browning gun without requiring changes in the gun proper.

M-4 .50 Caliber Machine Gun Assist Feed

The assist-feed as shown in Figures 13 and 15 contains as a power source a 110 volt a-c stalling motor, power-drill type, working through a torsion spring which drives a sprocket. This sprocket pulls the belt through rolls which give it a quarter turn to line up the cartridges from the rounds container with the gun axis. Each cartridge is pushed up against a stop built into the cover of the mechanism, from which it is released by the energy from the recoil of the gun. The energy in the torsion spring is great enough to snap the belt up, forcing the next cartridge in the belt against the stop. The spring is re-tensioned each time by the motor. The motor switch operates simultaneously with the gun trigger.

In field tests under Ordnance Department observation, the device performed satisfactorily, with the gun firing freely in its normal manner and the assist feed handling belts of 20 to 50 cartridges, even with additional weights of 25 to 30 pounds hung on the belt.

16.1.6 Turret Seat

The development of a functional seat was required for the gunner in the T-7 light tank turret, with design features permitting him to use all the guns and observation devices with the greatest ease and comfort.

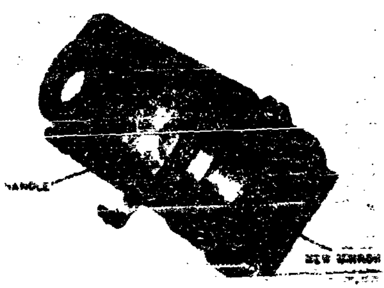


Figure 12. Magazine feed for protectoscope mirrors.

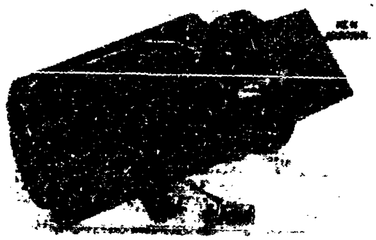


FIGURE 13. Magazine feed for protectoscope mirrors, new mirror being slid into place.

T-7 TURRET SEAT

These requirements were met by a seat enabling the gunner to shift to any one of three operating heights, slide forward or backward, and turn in a complete circle (Figure 16). The three operating heights are marked by three stops, one for using the 360-degree vision device in the turret roof, another for sighting the 37-mm gun and controlling the turret, and a third for using the rear machine gun. When the operator wishes to raise the seat, he supports himself on his feet and trips the handle; a strong spring lifts the seat, and a spring-impelled latch drops into place, locking it in position. When he wishes to lower the seat, he releases the latch and his own weight overcomes the spring, forcing the seat down until the spring-backed latch slips into the next slot, locking it in position.

The seat can be moved forward and back on slides with stops at each end and a locking lever to hold any desired position. It is capable of full rotation and adjustable for height in piano stool style by means of a central screw.

16.1.7 Turret Mock-ups

The development of the gun mounts, protectoscopes, and viewing devices for the T-7 and M-1 tanks made it necessary to modify the general turret design to accommodate these devices. Mock-ups for the T-7 turret, incorporating more sloping lines for the sides, and for the M-1 turret were prepared.

16.1.8 Centrifugal Air Cleaner

Soon after the introduction of motor vehicles to desert warfare in 1941, a need became apparent for a self-cleaning device to clean the air intakes of tank and truck engines. The static or oil-filter type of cleaner had not proved satisfactory, requiring a thor-

FIGURE 14. Machine gun turret feed, cover on.

FIGURE 15. Machine gun turret feed, cover off.

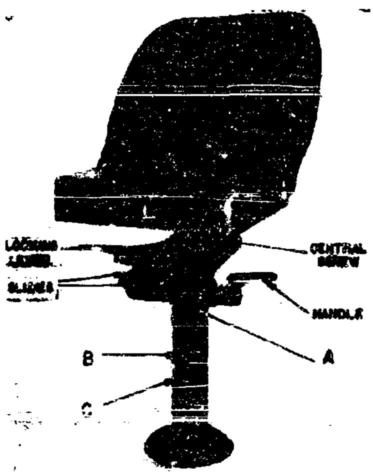


Figure 16. Model of turret seat with three stops for operating heights.

ough cleaning itself after a few hours of exposure to desert dust, and no suitable alternate type was available.

An investigation was therefore requested by Army Ordnance for the development of a self-cleaning centrifugal air cleaner to be used on such a vehicle as an M-3 medium tank and to meet the following chief specifications:

1. Volume of air flow at 2,000 rpm	670 cfm
2. Speed ranges	500–2,400 rpm
3. Maximum particle diameter to be passed by the filter	5 microns
4. Maximum space to be occupied	3,000 cu in.
5. Maximum weight	50–100 lb
6. Device to be self-cleaning	

The two standard types of rotors used in centrifugal separators are the tubular-type rotor and the disk-type rotor, the latter containing stratifying disks arranged in a stack of cones. After considering the dimensions allowable for the device, the size of the ducts necessary to carry sufficient air flow, and the position of the device in the tank, it was decided to make the rotor of the disk type, having a stack of conical disks with air flowing from the outside of the disks inward. Impeller blades were put in the inlet section of the centrifuge to bring the incoming air up to rotational speed before entering the periphery of the rotor.

The first model constructed, known as the L-5, was difficult to install in the M-3 tank, which was designed to accommodate a pair of static type filters. Accordingly, the L-8 centrifugal air cleaner was de-

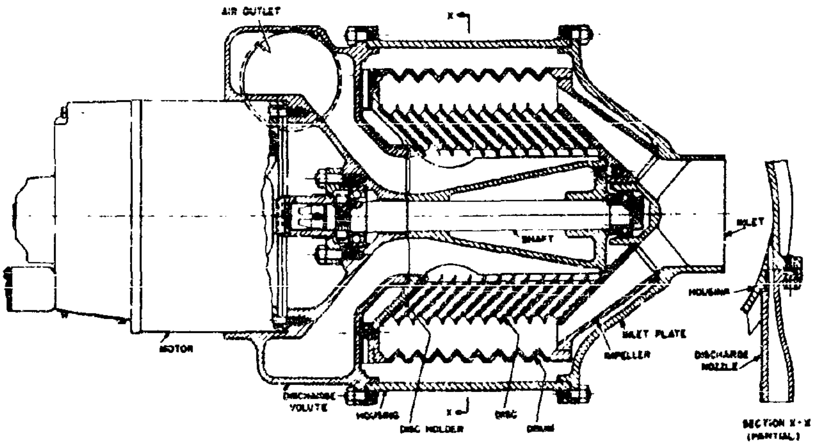


Figure 17. Cross section of centrifugal air cleaner.

signed as a smaller unit, with a capacity of 350 cfm and a maximum rotor speed of 8,000 rpm, able to handle half the air required by the Wright 975EC2 engine in the tank. Three models were built.

Laboratory tests on the L-3 were made by the so-called "impinger method" to determine the dust-separating ability of the cleaner. Similar tests were made at the air cleaner test laboratory of the Aberdeen Proving Ground at Aberdeen, Maryland. No field tests were performed.[5]

The construction of the L-3 cleaner is shown in Figure 17. The specifications are as follows.

1. Capacity	350 cfm
2. Diameter of intake	3.625 in.
3. Diameter of disks	7.5 in.
4. Number of disks	42
5. Disk spacing	0.5 in.
6. Disk stack up	6.0 in.
7. Angle of disks	45°
8. Maximum speed of rotor	8,000 rpm
9. Weight (with motor)	174 lb

The stationary parts of the cleaner are bronze castings, the rotor castings are aluminum alloy, the disks are spun of steel, and the shaft is steel mounted in SKF bearings.

The impinger tests indicated that the L-3 removes 98.66 per cent of the dust particles and 99.9+ per cent of the dust weight. Further analysis showed that of the small percentage (about 1.3 per cent) of particles not removed, about 5 per cent are more than 5 microns in diameter.

The tests at Aberdeen, made with an exceedingly fine artificial dust expressly designed for efficiency tests, showed that 97.1 per cent of the dust by weight is removed when the engine is idling, 93.9 at half air (1,800 rpm), and 93.6 at full air (2,200 rpm).

These figures show the L-3 cleaner to be superior to the static type cleaners at engine idling speed, less efficient at half air flow, which is the usual engine requirement, and still less efficient at full air flow. Figure 18 shows the relative performance of the L-3 cleaners and an oil bath static cleaner on a weight percentage basis.

An advantage of the L-3 self-cleaning centrifugal air cleaner over static type filters is its constancy of pressure drop. Its greatest single advantage is its relative freedom from servicing requirements. The L-3 automatically ejects the dust separated from the air, whereas the static types must be taken apart, cleaned, freshly oiled, and reassembled every day for optimum service. However, the L-3 will not extract a sufficiently high percentage of very small particles (less than 5 microns), and accordingly its use is not recommended for this duty.

16.1.9 Conclusions

No items developed in this project were put into production.

16.2 MOBILE ROCKET LAUNCHERS[c]

Summary

In cooperation with other divisions of NDRC, Division 12 recommended that the DUKW be equipped to carry rocket-launching devices and used to supply additional fire power for amphibious assaults. The Scorpion launcher designed in this research was incorporated in several DUKWs which were sent to the Southwest Pacific, while other units were dispatched to the European Theater of Operations. In the Pacific Ocean Areas, after a token rehearsal at Milne Bay in November 1943, the rocket-carrying DUKWs were used in the assaults on Arawe, Cape Gloucester, Saidor, and other island objectives, inaugurating the rocket beach barrage technique.

[c] Project "Scorpion."

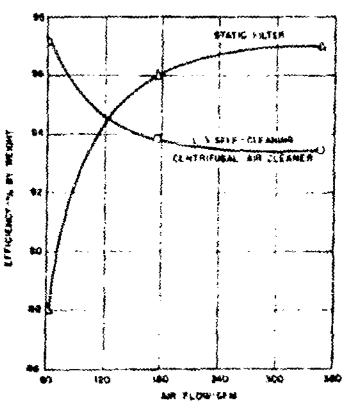


FIGURE 18. Comparison of performance of centrifugal air cleaner and static filter air cleaner.

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The construction of the L-3 cleaner is shown in Figure 17. The specifications are as follows.

1. Capacity	350 cfm
2. Diameter of intake	3.625 in.
3. Diameter of disks	7.5 in.
4. Number of disks	12
5. Disk spacing	0.5 in.
6. Disk stack up	6.0 in.
7. Angle of disks	45°
8. Maximum speed of rotor	8,000 rpm
9. Weight (with motor)	174 lb

The stationary parts of the cleaner are bronze castings, the rotor castings are aluminum alloy, the disks are spun of steel, and the shaft is steel mounted in SKF bearings.

The impinger tests indicated that the L-3 removes 98.66 per cent of the dust particles and 99.9+ per cent of the dust weight. Further analysis showed that of the small percentage (about 1.3 per cent) of particles not removed, about 5 per cent are more than 5 microns in diameter.

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[a] Project "Scorpion."

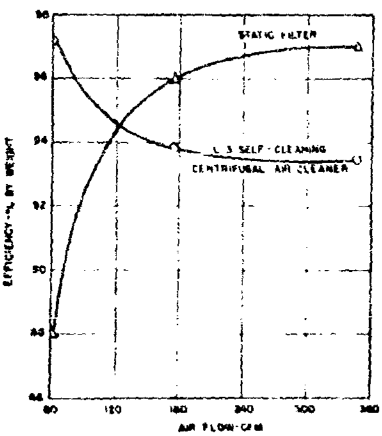

FIGURE 18. Comparison of performance of centrifugal air cleaner and static filter air cleaner.

16.2.1 The Problem

At the request of a special committee of the Joint Chiefs of Staff and the Joint Committee on New Weapons and Equipment, Division 12 undertook a study in October 1942 on the equipping of combat vehicles with rocket-launching devices. It was believed desirable that these devices be so designed that they could be used on various vehicles, amphibious or nonamphibious, and could also be removed for use on the ground.

PROCEDURE.

A preliminary survey of this problem resulted in a recommendation that the rocket launcher be devised for use on either the amphibious or the nonamphibious ¼ ton, 4x4 jeep. Later, however, the DUKW[a] was chosen as the basic vehicle because it could mount a greater fire power of rockets. The DUKW installation was then designed for the 1,100-yard 4.5-inch Beach Barrage Rocket [4.″5 BBR], which had already been brought to an advanced stage of development by the California Institute of Technology [CIT], a contractor under Division 3 of NDRC.

A fleet of DUKWs had already been assigned to the Second Engineer Special Brigade [2nd ESB], then completing its final training at Fort Ord, California, and preparing to embark for Australia. One of the brigade's DUKWs was sent to CIT and work began on January 19, 1943. Since the brigade was scheduled to embark in about a week, an installation was improvised from elements already available. This consisted of sheathing the cargo space of the DUKW with sheet metal for protection against rocket blasts, providing a protective sheet metal canopy over the cab, and then mounting three so-called "crate" launchers side by side across the center of the cargo space. Each crate, previously developed by the CIT group for firing a 4.″5 BBR from support boats, consists of four tiers of rails, with three sets of rails in each tier.

The CIT group completed the installation on the night of January 20, and the DUKW was then driven to Fort Ord for demonstration firings on January 22 and 23. Following the demonstration, the commanding general of the 2nd ESB reported that the barrage pattern was excellent and thereupon shipped the improvised rocket DUKW to the Pacific with his men. In return, he released two standard DUKWs to CIT for use in the further development of a launcher.

With more time available, it was possible to design a new launcher with a capacity of 144 rounds of 4.″5 BBR. By March 18, 1943, an improved version of this launcher had been manufactured as a proposed pilot model and was ready for test.[b] This launcher was composed of 12 separate units or subassemblies, each consisting of a rack of 12 5-foot tubes or barrels fixed in line fore and aft and inclined forward at a quadrant angle of 45 degrees (Figure 19). The lower ends of these barrels vented into a tube which formed the bottom of the rack and which was designed to stop the flame from the rocket blast, while small perfora-

[a] See Chapter 5 in this volume.

[b] This unit was manufactured by the General Motors Corporation, Detroit, Mich.

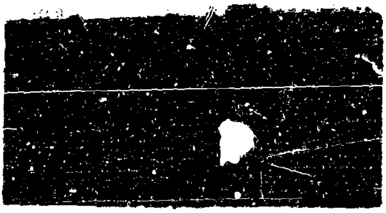

FIGURE 19. Early model of Scorpion rocket launcher for DUKW.

FIGURE 20. 4.″5 barrage rocket fire from Scorpion.

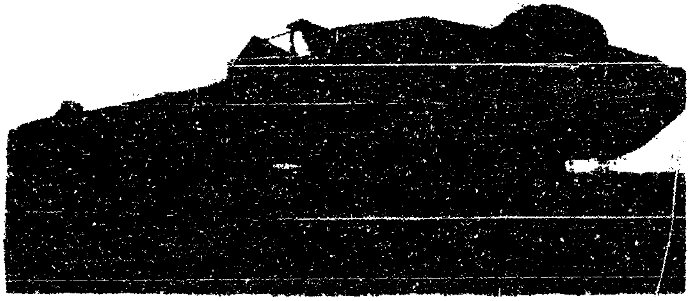

FIGURE 21. Improved Scorpion rocket launcher installed on DUKW.

tions in the end permit the blast gases to escape. Field tests (Figure 20) indicated the need of various minor modifications, including the reduction of the number of barrels in each unit from 12 to 10, giving a total capacity of 120 rounds (Figure 21). A fire control box designed by the manufacturer was added so that the codriver could use a motor-driven selector switch to "ripple fire" a complete salvo of 120 rounds in 1 minute or to fire single rounds as desired. This launcher was designated the CIT Type 6 Mod 1 launcher for the 4.5 barrage rocket.[3] Four of these units were then manufactured and shipped overseas early in August 1943 to the 2nd ESB which, having completed its training in Australia, had joined the combined Australian and American forces operating along the coast of New Guinea.

At the same time, 10 additional launchers were obtained to meet urgent cable requests from the European theater, and subsequently about 150 launchers were ordered for use in future European operations.

A second type of launcher was later developed to enable the DUKW to fire 7.2 rockets. This project, undertaken at the request of NDRC to deal with the special demolition problems which would be involved in the invasion of Europe, was directed almost entirely by Division 3.[a] After a series of demonstrations at Fort Pierce, Florida, in February 1944, during which military observers reported favorably on its operation, this device went into production. No field requirement, however, was ever formally confirmed, and the informally requested installations—approximately 100—were never used.

16.2.3 Results

Even though the five rocket DUKWs sent to the 2nd ESB had been urgently requested for virtually immediate use, representatives of Division 12 found on arrival at Milne Bay in New Guinea that they had been warehoused there for about 3 months. The NDRC representative then staged a token rehearsal of these units in November 1942 and indicated to the military authorities the possible tactical uses of these vehicles. On December 15, 1943, two of these rocket DUKWs spearheaded the landing at Arawe on New Britain Island, giving the 2nd ESB the distinction of being the first to use barrage rockets in an amphibious operation in the Pacific. At daybreak the DUKWs preceded the waves of amphibious tractors and landing craft and poured out a deadly fire on the beach on which the landing was made. Because of the configuration of the beach the rocket DUKWs were able to continue the fire until the leading wave of amphibious tractors was only 200 yards from the beach proper. Only scattered shots were received from the beach as the heavy rocket barrage obviously smothered the Jap defenders. The fire power which these rocket DUKWs laid on the beach just at the last moment before the waves landed was so destructive, it was reported by the commanding general of the brigade, that their example was followed in all later

landings in the Pacific. For the next 6 months, the rocket DUKWs were used by the 2nd ESB in nearly every amphibious operation to which this group was assigned. In the landing on Cape Gloucester in New Britain, they laid down a preparatory barrage for the assault on a beach objective. They were used also in the Saidor landing, the Hollandia operation, the assault on Tanamerah, and the invasion of Biak. In many of these operations, after the DUKWs had laid down their barrage to cover the initial landings, they were used regularly for "end runs" to extend the beachhead. They were used to destroy enemy barrages in water too shallow for PT boats. In some cases they were also driven ashore and used as the troops advanced inland, taking on the function of small tanks and knocking out enemy gun emplacements and strong points which were holding up infantry advances.

The rocket DUKWs were seldom used after the late spring of 1944. This resulted partly from the fact that no more replacement launchers were forthcoming, but especially from the fact that the 2nd ESB had found the LVT (Buffalo) better suited to its general needs for an amphibious rocket vehicle. Although the LVT has less rocket-carrying capacity than does the DUKW, it was found to be more able to negotiate reefs, pot-holes, and muddy terrain, and its rocket fire for landing operations could be better supplemented by that of other rocket craft which were a regular part of the battalion's support battery.

Chapter 17

LAND VEHICLE STUDIES

17.1 TANK NOISE REDUCTION[a]

Summary

In an effort to reduce the noise of production models of the M-5 light tank, tests and modifications were made on a number of light and medium tanks manufactured by Marmon-Herrington and General Motors. As a result of these studies, it became possible to reduce the noise of the M-5 light tank to approximately one-third of its usual level.

This was accomplished in part by acoustic treatment of the crew compartment, the engine compartment, and the air intakes and outlets, and by the use of the most quiet types of tracks, but largely by the application of an adequate muffler and the installation of suitable rings or blocks to absorb the shock of the impact of the track blocks on the sprocket teeth.

No practical use was made of either the sprocket teeth silencers or the improved mufflers, although, largely as the result of renewed tactical requirements for night flanking during the Battle of the Bulge in the Ardennes, military interest was temporarily renewed in the development of quiet mufflers.

17.1.1 The Problem

During the early part of 1941, it became apparent to the U. S. Army Ordnance Department and to several tank manufacturers that tanks currently coming off the production lines were excessively noisy. This noise included not only "tactical" or outer noise, which would serve to warn enemy observers of the proximity of the tank, but also "crew environment" or inner noise, which interferes with intercommunication by crew members and presumably induces fatigue.

Research was consequently instituted first to measure the noise produced by selected light and medium tanks, with special attention to that produced by their tracks and sprockets, and then to develop effective methods of control which could be applied without radical changes in tank design.

It had already been reported by other workers that, in so far as tactical noise is concerned, the most obnoxious are the high-frequency noises resulting from sprocket clatter, and accordingly it was felt that particular emphasis should be placed on controlling this source.

17.1.2 Procedure

Preliminary listening tests were conducted on the Marmon-Herrington CTL-6 light tank and CTM-3TBD medium tank, which were equipped in turn with steel tracks, rubber block tracks, and continuous rubber tracks with steel idlers, and then run over concrete, gravel, and dirt surfaces. Sound levels were determined with a microphone placed in eight different positions inside and outside each tank and connected to equipment which measured the levels in different frequency bands. It was found that the track with its associated idlers and sprockets is the principal source of noise, and that any noise reduction of these two tank models must involve an improvement of these components.[b]

This investigation was then continued on the General Motors M-5 light tank.[c] The first measurements, including objective sound measurements and "jury tests," with observers judging the detectability of tanks, pointed to a number of individual factors which contribute in different degrees to tank noise. Each of these factors was considered in turn and an effort made to find the most practical solution.

Sprocket Noise

In order to determine the means by which sprocket clatter is generated, high-speed motion pictures were made under operating conditions,[d] and particular attention was directed to the point of track engagement. These indicated that, as far as approach to the sprocket is concerned, the track fails to act as a flexi

[a] Project DB-19.

[b] These measurements were made by the Cruft Laboratory, Harvard University, Cambridge, Mass., under the National Research Council Committee on Sound Control, and reported in reference 1.

[c] This investigation was conducted by the General Motors Corporation, Proving Ground Section, Milford, Mich., under OSRD contracts OEMsr-360 and OEMsr-870.

[d] Made by Edgerton, Germeshausen and Grier, Cambridge, Mass., under OSRD contract OEMsr-26.

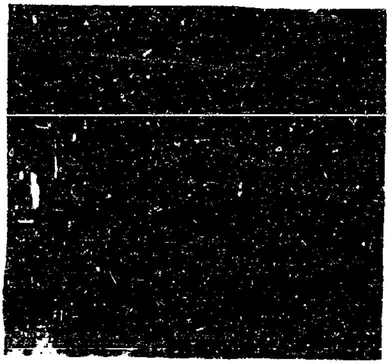

FIGURE 1. Rubber rings installed on M-3 light tank to reduce sprocket noise.

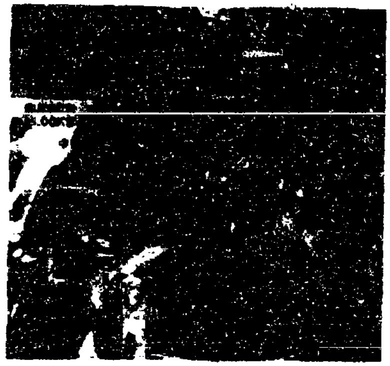

FIGURE 2. Rubber blocks installed on M-3 light tank to reduce sprocket noise.

ble band. Instead of moving toward the sprocket along a line tangential to the pitch circle, the approaching track blocks come in above the tangential line, and on engagement swing in radially to seat on the shoulders of the sprocket teeth. This action is probably due to the stiffness of the track and the track joints. The impact with which the inward radial motion ends was tentatively considered as the principal excitation for sprocket clatter, and subsequent tests tended to confirm this view.

In a preliminary attempt to silence the sprockets, damping material was applied to the complete sprocket assemblies in the form of a half-inch coating of an asphalt-sand mixture which was baked on the hubs and teeth, both inside and out. This coating was quickly found to be impractical and perishable, and moreover gives a reduction of only about 3 db.

It was next determined that no measurable improvement could be obtained by cutting away the shoulders on the sprocket teeth.

The final modification involved the addition of rubber shock absorbers. In one case the absorber is in the form of a rubber ring held between metal bands and designed to bear the radial loads at the sprocket while the tangential driving forces are borne by the sprocket teeth.[c] (See Figure 1.) In the other it consists of small rubber blocks bonded to metal mounts which fit in between the sprocket teeth and are welded in place (Figure 2).

Listening tests were run on the M-3 tank equipped with these modifications and with different kinds of tracks.

MUFFLER NOISE

Several muffler designs were tested and compared with the production mufflers currently being installed on the M-3. With twin mufflers of the same size and shape as those used on production models, any attempts to reduce noise resulted in most cases in higher back pressure and less satisfactory tank performance. The most satisfactory of the double muffler type was found to be the Hayes No. 2A159.[d]

Much better results were achieved with a single muffler, particularly the Nelson T-1619, with a single tail pipe for the whole engine (Figure 3).[e] Moderate improvement could be obtained by adding to the production muffler a tail pipe 2½ inches in diameter and 20 inches long.

MISFIRING NOISE

In production model tanks, it was found that when the throttle is closed at high engine speeds, the engine misfires and then ignites the unburned charge in the exhaust manifold. The correction of this noise

[c] In this form the rubber rings are analogous to those on the Canadian Mark III Valentine Tank and serve the same purpose.

[d] Manufactured by Hayes Industries, Inc., Jackson, Mich.

[e] Manufactured by the Nelson Muffler Corp., Stoughton, Wis.

was not undertaken in this investigation but referred to the manufacturer for appropriate action. A de-foaming device was designed by the manufacturer for the M-5 engine.

Engine Compartment Noise

A first attempt at reducing the tactical noise from the engine compartment consisted of the application of large conduits or ducts lined with sound-absorbing material. These were fastened to the exterior of the tank, one being applied to the engine air-intake opening and the other to the exhaust and cooling air outlet, as shown in Figure 3.

To reduce engine compartment noise reaching the crew compartment, the oil coolers were enclosed and the engine compartment sealed except for an absorbent-lined duct through which cooling air could be drawn. This duct replaces the propeller shaft cover of the production tank. Air enters the duct through openings near the transmission casing and travels parallel to the propeller shaft toward the rear, where it branches out into the oil cooler enclosures.

Sound-Absorbing Lining

As a further step in reducing inner noise, a highly absorbent layer of ½-inch hair and asbestos felt was applied to all the accessible wall surfaces. The production tank, with its hard metallic interior surfaces, offers negligible sound absorption, and consequently it was expected that the introduction of even moderately effective sound-absorbing material would give appreciable improvement.

Track Rumble and Hull Vibration

A major source of low pitched noise in the tank interior was traced to the relation between the bogie wheels and the tracks. In the production track, a gap exists between successive tread blocks, and the bogie wheels tend to sink into this gap as they cross from one block to the next. If, as in the production M-5 light tank, the spacing between wheel centers on the same bogie assembly is equal to an integral multiple of the tread block length, both of these wheels sink into the gaps simultaneously, and their motions are in phase. Under these conditions a strong vibratory force is transmitted through the spring suspension to the hull of the tank and results in a low-frequency rumble which tends to vary considerably in intensity as the two tracks move relative to each other. The vi-

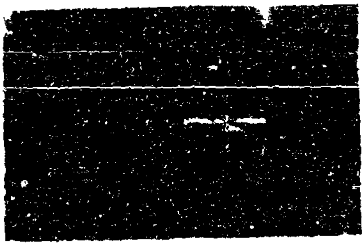

Figure 3. Installation of Nelson 1-1619 muffler on M-5 light tank.

Figure 4. Installation of sound-absorbing ducts on M-5 light tank.

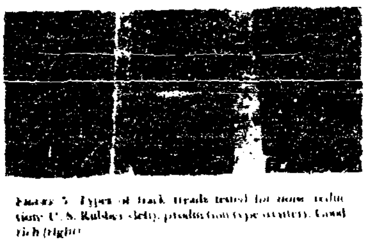

Figure 5. Types of track treads tested for noise reduction: U. S. Rubber (left), production type (center), Goodrich (right).

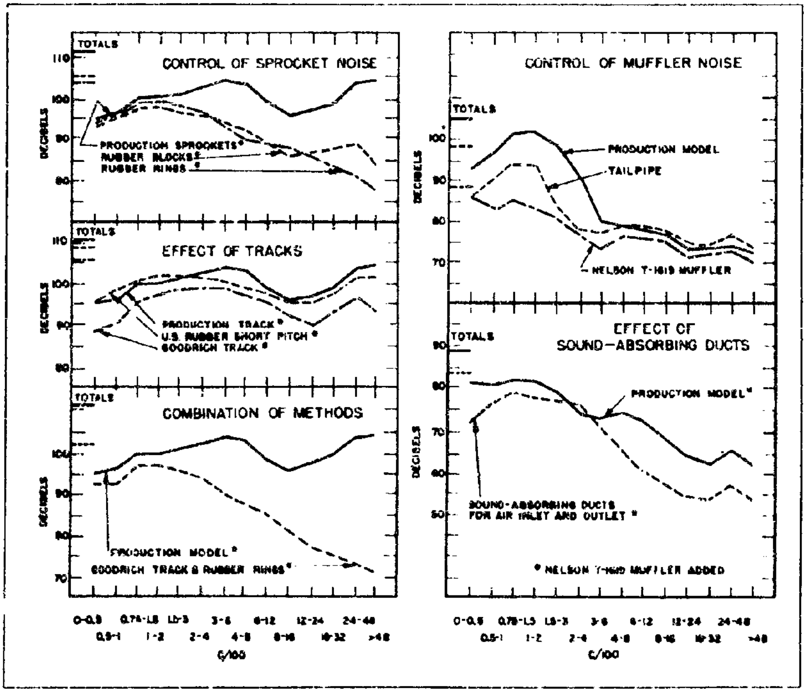

FIGURE 6. Effects of control measures on tactical noise of M 5 light tank.

bration also causes severe rattling of the turret and other parts of the tank at certain speeds.

In order to reduce the low-frequency bogie wheel rumble by producing an out-of-phase relationship between the bogie wheel motions, a U. S. Rubber Company track with a shorter block length was substituted for the standard track. In another attempt, a B. F. Goodrich Company track presenting a much smoother surface to the bogies was tested (see Figure 5).

17.1.3 Results

The effects of these various modifications in reducing tactical noise are shown in Figure 6. An average over all reduction of more than 6 db is obtained on sprocket noise by use of the rubber rings and of about 5 db by use of the rubber blocks. The reduction is particularly noticeable in the higher frequencies.

With muffler noise measurements taken 15 feet from the rear of a stationary tank and with the engine idling at 2,000 rpm, an over all reduction of about 7 db is obtained by addition of a tail pipe to the production muffler and of more than 18 db by substitution of the Nelson T-1619 muffler. The effects are most noticeable in the lower frequencies.

An over all reduction of more than 4 db results from adding sound absorbing ducts for air inlet and outlet, with measurements made behind the station

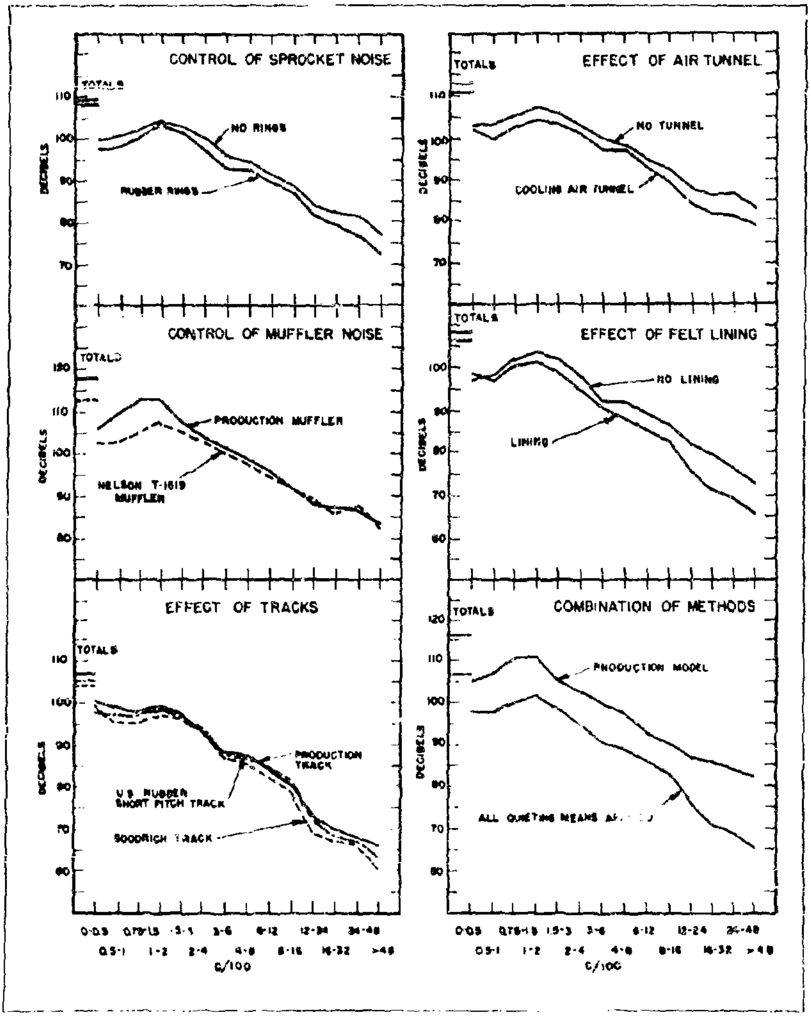

FIGURE 7. Effects of control measures on inner noise of M-5 light tank.

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any tank already equipped with the 1-1619 muffler and the engine idling at 1,500 rpm.

Use of the Goodrich smooth rubber track gives an over-all reduction of about 5 db on a tank already equipped with the 1-1619 muffler.

A combination of these controls gives an over-all reduction of about 8 db.

The results in reducing inside noise are illustrated in Figure 7. An over-all reduction of more than 5 db is given with the 1-1619 muffler, about 1 db with rubber rings, about 1 db with felt linings, about 1 db with an insulated cooling air tunnel, and about 2 db with the Goodrich smooth rubber track. The combination of all these controls gives an over-all reduction of about 9 db.

In jury tests, seven observers recorded the time at which they first heard the tank—either an unmodified production model or an experimentally modified tank—approaching across a turf field. Rough comparisons indicated that the unmodified tank could be heard on the average at 800 yards, and while starting and shifting gears at 3,270 yards. Addition of the Nelson muffler reduced this average to 615 yards, and the installation of sound-absorbing material around the tracks and around the cooling air inlet and outlet reduced it still more to 515 yards.

Neither the newly developed sprocket teeth silencers nor the improved muffler found application to production tanks. Very late in the war, the Army requested further study of the sprocket teeth devices, but this was cancelled soon after the surrender of Germany. Considerable interest developed in mufflers shortly after the Battle of the Bulge in the winter of 1944-45, and a project was set up to test commercially manufactured mufflers for use in quieter tank operations. Although satisfactory mufflers were designed and built, they were not released for production.

17.1.4 Conclusions

By combining the noise reductions obtainable by rubber sprocket rings or blocks and good mufflers, the external or tactical noise of the M-3 light tank can be reduced at least 8 db over the whole frequency range, and nearly 10 db over all. This corresponds to a reduction of the sound pressure to one-third of its original value. It also means that the average audibility distance will be reduced to perhaps one-third of that for a production tank, depending on the ambient noise at the listening point.

Further reduction in the tactical noise can be obtained by a sound-absorbing lining for the engine compartment, by track and suspension changes, and by absorbing ducts for the engine air intake and outlet. However, the elimination of misfiring and sprocket clatter and the installation of better mufflers remain the prime requirements for satisfactory noise reduction over the whole frequency spectrum.

In the case of inner noise, low frequencies are diminished by muffling and by track changes, and middle and high frequencies are reduced by sound-absorbing linings and sprocket rings, and by the sealing off of the engine compartment. The net result is a reduction sufficient to enable the crew to carry on intelligible conversation throughout the speed range of the tank.[10]

The use of rubber rings, while excellent from a noise reduction point of view, is not a satisfactory solution from a practical point of view. The clearance between sprockets and tank hull is excessively diminished, and several rivets cause interference with the extended track guides. It appears that the use of bonded rubber blocks is more practical, giving equivalent noise reduction without introducing interference problems. Although the rubber blocks as used prove somewhat less quieting at high speeds than do the rubber rings, a slight redesign should be able to restore the full quieting efficiency.[13]

Although it had been reported earlier by other workers that the high-frequency sprocket clatter of a tank is the most important source of noise in enabling distant observers to detect it, this is not confirmed by the present investigation. In general, it appears that the low frequency of muffler noise is at least as important. Only when the ambient noise is rich in low frequencies does the detectability of a tank depend primarily on sprocket noise.[5]

17.2 REDUCTION OF BOUNCING IN TOWED GUN CARRIAGES

Summary

Design changes in (1) gun carriage suspension, including increased wheel travel, increased width, decreased spring rate, and increased damping, and in (2) gun carriage tow connections, including damping, have been recommended to give needed improvement in performance during towing.

17.2.1 The Problem

Observation indicated that two-wheeled gun carriages without spring suspension occasionally undergo serious bouncing when towed on a hard road. In addition, four-wheeled carriages with spring suspension, including 37- and 47-mm types, have been found subject to damage when towed over a rough road.

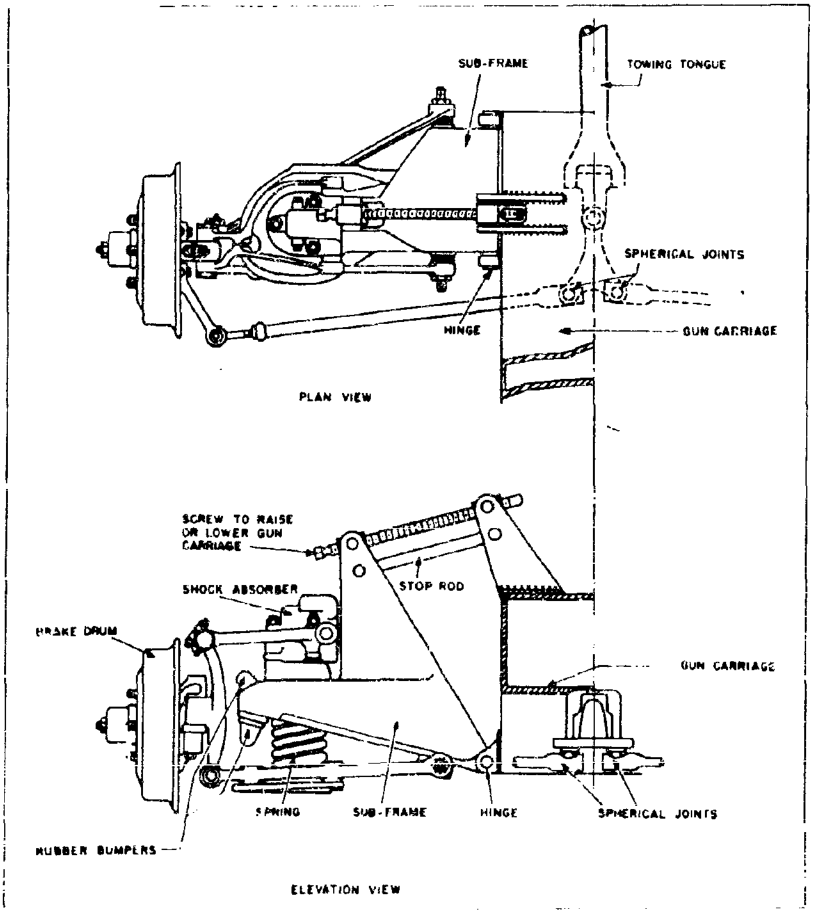


FIGURE 8. Proposed Design A for four-wheeled gun carriage suspension.

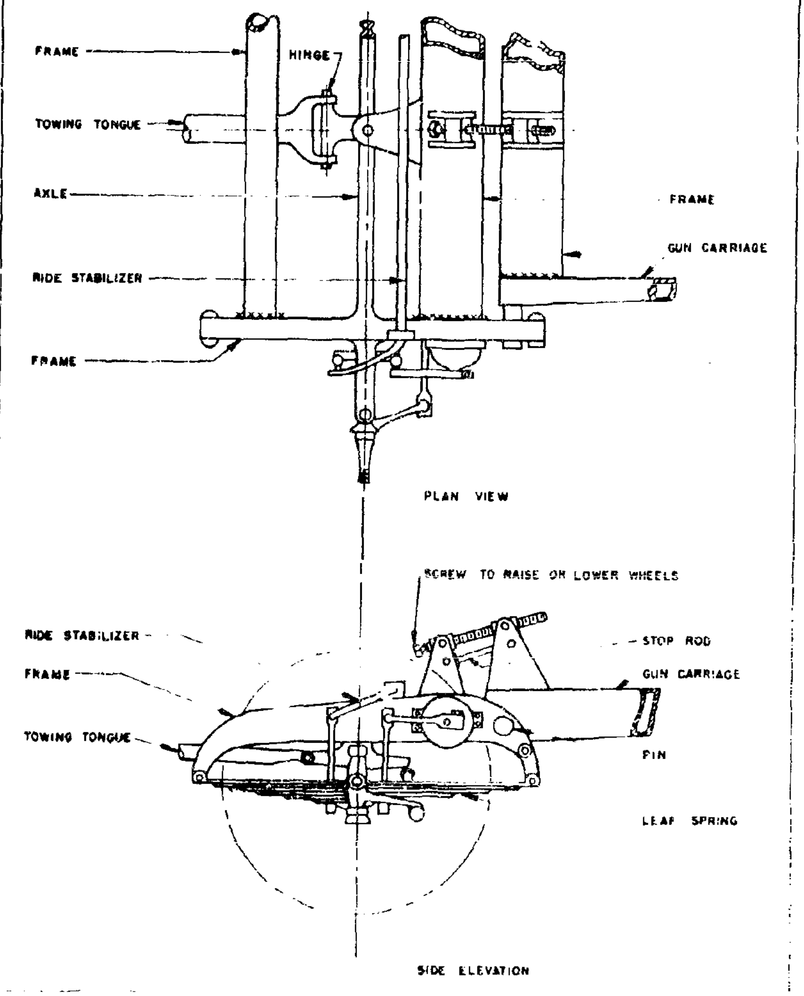


FIGURE 9. Proposed Design B for four-wheeled gun carriage suspension.

An investigation was required to devise design changes which would eliminate or greatly reduce this characteristic.[8]

11.2.2 Conclusions

Two-Wheeled Carriages

In the case of two-wheeled carriages without spring suspension, the damping attending free vibration on a hard road is so limited that serious bouncing would be expected as a result of wheel unbalance or of bumps having a component of period equal to the natural period. In the case of a soft road, such a resonance would be undoubtedly much less severe because of the damping in the road material.

Even without radical changes in the design of the two-wheeled carriage, considerable improvement may be obtained by adding vertical flexibility between the carriage and the point of attachment to the towing vehicle, and by providing damping across this flexibility. If this damping were large enough, it would tend to eliminate rather than merely reduce the possibility of a self-excited bouncing on a smooth road, and it would tend to reduce but not eliminate the amplitude of vibration on a hard, rough road. It is expected that the addition of such damping would not improve performance over a soft road.

Four-Wheeled Gun Carriages without Spring Suspension

No material improvement in this type of carriage is suggested. It seems likely that, because of pin friction, considerable damping is already present to reduce almost any mode of bouncing. Because of this, there seems to be no need to add damping either as proof against periodic bouncing on a smooth road or as a means to reduce bouncing on a hard, rough road.

Four-Wheeled Gun Carriages with Spring Suspension

In a study of the 37-, 40-, and 90-mm guns, it was found that, in the case of at least the first two, damage has occurred from hitting the stops at the ends of the spring travel of the wheel. This could be reduced by (1) increasing the damping by the addition of shock absorbers, (2) increasing the travel between stops, (3) providing deep resilient bumpers instead of stops, and (4) increasing the spring rate. Any one of these steps or a combination of them would be expected to have a beneficial effect. At times when there is no impact, steps 1 and 2 would usually improve the ride but generally the greater the spring rate, the harder the ride. On the other hand, if the spring rate is reduced and the tendency to hit the stops is compensated by steps 1 and 2, the ride is improved but the point is soon reached where the side sway on turning becomes excessive. Side sway can be minimized by using as wide a wheel spread as is practical. It can also be reduced by using a torsion spring connection between wheels, but this increases the spring rate for bumps on only one side.

A further study of the 37-mm gun carriage indicated that the carriage would tend to squat when the brakes were applied, and that the slotted joint used in current models is somewhat vulnerable to dirt and wear.

In addition to design changes of increased wheel travel, increased width, decreased spring rate, and increased damping, it appears that the method of raising and lowering the wheels could be simplified. It also seems that the same type of design should be used on all sizes of carriages, at least up to those using two tires per wheel. Two carriage suspension designs have been suggested, both using parts taken from standard automobiles.

In the scheme shown in Figure 8, Chevrolet front-wheel springs, brake drums, shock absorbers, and rubber bumpers are mounted on the subframe, which is hinged at the frame of the gun carriage. The wheel may be raised or lowered by rotation of a special screw. When the wheel is lowered, a rod stops the travel in the ride position. The steering from the tongue is more or less conventional. The spherical joints are placed so that the wheel may be raised without interference.

Figure 9 shows a scheme which is adaptable either to the leaf spring suspension illustrated here or to the knee action type of wheel suspension. The leaf spring, ride stabilizer, axle, etc., are all mounted on the frame which is hinged on the main frame. The wheels (not shown) may be raised or lowered by rotating the screw. A rod serves as a stop when the wheel is lowered. The steering is conventional. The towing tongue is hinged at a point which will not interfere with rotation of the frame about the pin.[27]

[8] This investigation was undertaken by the Baker Manufacturing Co., Evansville, Wis., under OSRD contract [illegible]

Chapter 18

SPECIAL DEVICES

18.1 LANDING WHEEL BRAKES

Summary

IMPROVED aircraft brakes with a capacity of energy absorption in the form of heat of 25,000 ft-lb per sq in. of braking surface have been developed to meet the specifications for such heavy bombers as the B-17, the B-24, and the B-29. This achievement, marking a threefold increase in capacity, has resulted largely from careful planning, cooperative effort, and exchange of data. The use of powdered metals in brake linings has been of great importance, as has the improved design of brake structures.

18.1.1 The Problem

In May 1941, an investigation was undertaken on expanding, contracting, and disk-type mechanical brakes, together with recommendations for increasing their braking capacity and reducing their size and weight.[a] When the study began, it was generally accepted that 6,000 ft-lb per sq in. of braking surface was the maximum that could be absorbed and dissipated in the normal stopping time. This limit, it had been reported, could not be materially exceeded without warping, shrinking, and cracking the plates, as well as very rapidly deteriorating the lining. Several types of cast iron and laminated steel plates had been developed, but gave only minor improvement.

Meanwhile, however, the Armed Services were planning the construction of very heavy bombers with unprecedented weight and landing speed. Specifications for such planes as the B-17 Flying Fortress, the B-24 Liberator, and the B-29 Superfortress called for braking capacities of 14,500 ft-lb per sq in.

18.1.2 Procedure

To aid in meeting these specifications, the National Research Council acted as a coordinating agency, securing cooperation from the industry, formulating plans for investigation, obtaining and transmitting necessary information,[1] suggesting design modifications, and urging development along specific lines. Funds were available to subsidize a certain amount of experimental work, but it was found that industry preferred to bear the costs of its own research, and this policy was encouraged.

The first extensive research program was directed toward obtaining materials with thermal conductivity high enough to remove the heat from the rubbing surfaces before the temperature would rise to destructive values. Powdered metal appeared to have the desired heat conducting ability, and was tried in several forms but at first without success. It was then suggested that the powdered metal in a $\frac{1}{16}$-inch thick facing be fused to a rolled copper plate. In tests with an Adamson dynamometer, these plates made 313 successful runs at a load of 10,000 ft-lb per sq in., 100 at 15,000, 61 at 20,000, and 10 at 25,000 before the test was discontinued.

New linings were required to work with these powdered metals, and these were successfully developed by several lining manufacturers. Improvement also became essential in the physical characteristics of the steels used for the shells and of the cast iron alloys, and these, too, were made by the industries.

18.1.3 Results

With the demonstration that the unit loading of an aircraft brake is not limited to the previously assumed 6,000 ft-lb per sq in. of rubbing surface, research was stimulated on a reassessment of other braking factors, and on the development of actual brakes for installation on aircraft. The resulting new products are now in service.

One small brake for a 7.50x10-inch wheel, originally rated at 4,000 ft-lb per sq in., has been equipped with a powdered metal facing and is rated at better than 7,000. Another, with powdered metal and with one of the new brake linings, operated satisfactorily on the B-19, and is now being manufactured in the smaller sizes with a claimed unit loading of 10,000 ft-lb per sq in. and a probable loading of 15,000. A third has passed complete load tests at 19,000 ft-lb per sq in.

[a] This investigation was conducted by the National Research Council, Division of Engineering and Industrial Research, the Society of Automotive Engineers, and representatives of the manufacturers and branches of the military services concerned.

Another on a 56-inch wheel was run at a load of 14,450 ft lb per sq in. of rubbing surface (totalling 10,000,000 ft lb) at a landing speed of 123 mph and in a stopping time of 15.25 seconds, and successfully passed 100 consecutive test stops.

18.1.4 Conclusions

Adequate aircraft brakes have been made available for the planes which were in quantity production when this study was terminated.[a] Experimental data and other information have been accumulated which should make it possible to meet requirements of the new and larger planes still in the stage of design and development. For given size and weight, brakes can be made with capacities at least three times that which they had when this research project was started, and the end is by no means in sight.

This has resulted largely from careful planning, cooperative effort, and exchange of data rather than from radically new principles of operation. Particular consideration was given to problems of heat transfer, suitable design to provide for inevitable expansion and contraction, and the development of new friction materials. No radically new brake designs or ideas were uncovered that could withstand the test of experienced scrutiny.

Powdered metallurgy has played a very important role in producing friction surfaces which eliminate "grab" and maintain an approximately constant friction coefficient over a wide range of temperature. Only a beginning has been made in the determination of the properties of various possible mixtures. This research should and doubtless will be continued.

18.2 BOMB RACKS[b]

Summary

In an attempt to improve on the Mark 51 Mod 7 bomb rack used by Navy bombers, two new designs, the Mark 51 Mod 11 and the Mark 51 Mod 12, were prepared and a small number of units delivered to the Bureau of Ordnance. In preliminary trials, they appeared to offer some improvements over the older model both in releasing and in arming the bombs.

[b] Project NO-235.

18.2.1 The Problem

Reports of serious operational service failures of the Mark 51 Mod 7 bomb rack prompted an investigation to determine as rapidly as possible the causes and conditions for failure and to design equally rapidly an interim device which would meet an urgent need for a dependable bomb rack.

18.2.2 Development of Mark 51 Mod 11 Bomb Rack[c]

PROCEDURE

Laboratory tests of production models of the Mark 51 Mod 7 rack revealed several types of failure, including failure to release and to arm the bomb at low temperature, a tendency to release by vibration, and a condition in which the bomb failed to disengage from the hooks after it had been released.

Failure to release the bomb at low temperature was due chiefly to the stiffening of a rubber sealing cap which effectively resisted the release solenoid force. The release solenoid was found to be inadequately designed for such a critical item.

Failure of the electric arm and safe function was due to inadequate solenoid and return spring force to overcome icing resistance at low temperatures.

The use of tectyl rust preventive contributed to the failures of both the release and arming functions. Tests in which failures were observed were made on racks cleaned with tectyl.

The tendency of the rack to release under vibration was discovered to be due to play allowing the release solenoid plunger to hammer against the release lever.

The type of failure in which the bomb failed to disengage from the hook after release of the rack was found to be due to a basic error in the location of the hook pivot point in the original rack. As a result, the friction of the hook in sliding out from under the bomb lug could effectively oppose the opening of the rack.

Since the relocation of the hook pivot point would have involved a complete redesign of the rack frame and mechanism, which would have been too time consuming for an interim device, the steps taken to correct this type of failure were confined to modification of the shape of the hook by providing a 7½

[c] This investigation was conducted by the Douglas Aircraft Company, Inc., El Segundo, Calif., under OSRD contract OEMsr-1195.

degree downward slope to the bomb lug carrying surface, and later the local induction hardening of this surface to reduce brinelling and friction. Strength tests of numerous hook samples indicated that the induction hardening should be carried out carefully to avoid introducing brittleness and weakening the hook.

Rack components designed to correct the faults noted above were built, tested, and installed in five sample racks, which were delivered to the U. S. Navy Bureau of Ordnance for testing. Although the modified racks were basically satisfactory in performance, the Bureau of Ordnance requested further design changes involving the arming retainer housing, the bomb hooks, and the electric arming control. The introduction of a specific arming solenoid coil temperature limitation at an increased voltage necessitated considerable redesign and testing in an effort to meet the heat requirement and yet to retain sufficient solenoid pull for cold weather operation.

In the course of the investigation, in which a large number of racks were observed completely dismantled for cleaning prior to installation on airplanes, there was considerable evidence of faulty manufacture and of a low standard of inspection on the functional parts.

RESULTS

The Mark 51 Mod 11 bomb rack, incorporating all Bureau of Ordnance requirements, was constructed as shown in Figure 1, and eight units were submitted to the Navy.[c] The upper part of the illustration shows the old Mod 7 rack with the upper side made of transparent plastic and portions of some parts cut away to reveal internal mechanism and construction. In the lower part are the redesigned parts to replace corresponding parts in the older model.

Shown here are the wire cover (A), the hoist slot cover plate (B), the release unit assembly with redesigned solenoid (C), grommets for release solenoid wiring (D), control cable bushings (E), latching screws (F), release solenoid wiring with quick disconnects (G), redesigned arming unit assembly, shown here with arming retainer pull-out guard (H), the hook as redesigned by the Bureau of Ordnance (I), the reworked hook from the Mark 51 Mod 7 rack (J), hook pivot pin washers (K), and hook pivot pins (L).

In laboratory tests, the release unit of the new rack appears to be thoroughly dependable for low temperature operation and has no tendency to release from vibration under 3,000 rpm and under .030 inch total displacement. The solenoid pull required to release the rack has been reduced. The solenoid force available has been increased, as have both the theoretical minimum load on the rack and the theoretical minimum sway brace torque which can prevent electric release.

The dependability of the arming unit for low temperature operation has been improved, the initial net solenoid thrust available to "arm" the unit has been increased, the maximum return spring force available to return the plunger from "Armed" to "Safe" position has been more than doubled, and the maximum coil temperature of solenoid for continuous operation has been reduced from 135-155 C to 100.5 C.

The bomb hooks have a hardness of 54-58 Rockwell C, as compared to 30-42 for the old model, there is no tendency to hang up under load after release, and the approximate average breaking load for a single hook has been decreased.[a]

18.23 Development of Mark 54 Mod O Bomb Rack[d]

PROCEDURE

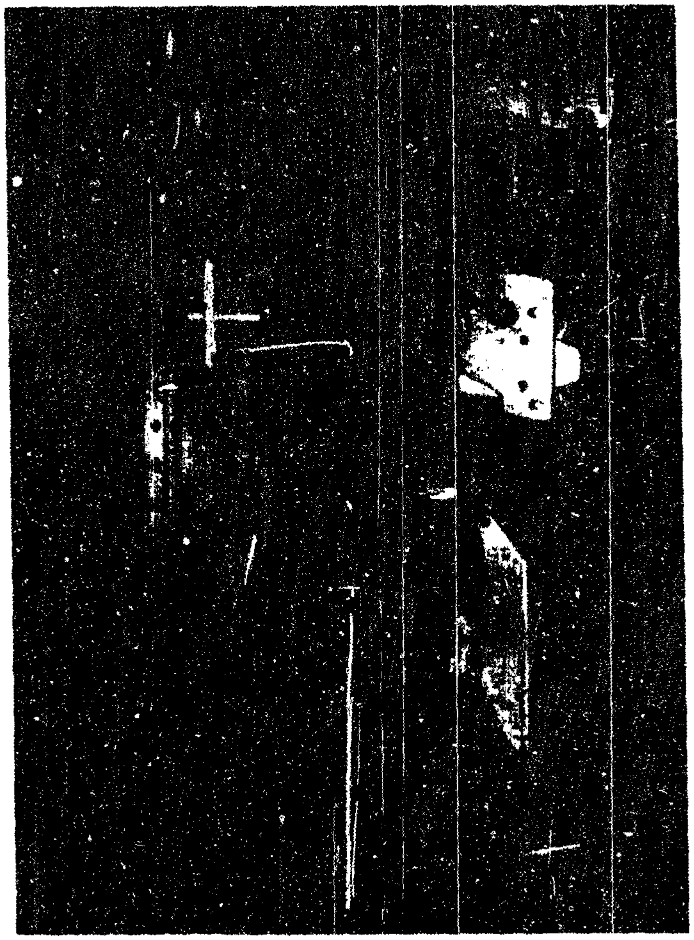
An independent investigation of the Mark 51 Mod 7 bomb rack led to a number of modifications. Enclosures were added where possible to protect against dirt and ice. Materials were chosen to give the least galvanic action. All linkages were analyzed with and without friction, and a coefficient of 25 per cent was used to provide sufficient margin in all but extreme cases. To reduce the effects of seizure, sticking, and friction, all parts were pivoted wherever possible and rectilinear motion was avoided except in the solenoid plunger and compression springs. The design was made so that dimensional accuracy would not be too important and would have only a minor effect on operation. Unit assembly of parts acting together was carried out in the two solenoid mechanisms.

The new rack designed according to these general specifications was delivered to the Bureau of Ordnance for testing.

RESULTS

The design of the new Mark 54 Mod O bomb rack is shown in Figure 2. The bomb is held in place by

[d] This investigation was conducted by the I-T-E Circuit Breaker Company, Philadelphia, Pa., under OSRD contract OEMsr-1333.



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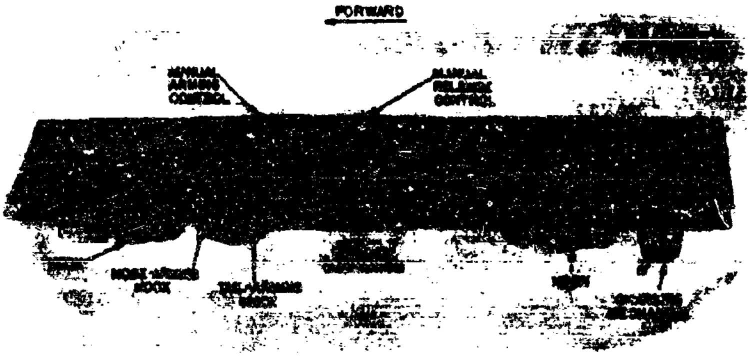

FIGURE 2. Mark 51 Mod 0 bomb rack.

two independent hooks on 14-inch centers, locked by two dead-center roller latches which are actuated by means of a single impact-producing linkage. With this design it is possible for one hook to be latched independently of the other, but if latching is not complete, release of pressure on the bomb-hoisting cable will immediately lower the bomb.

The action to release the bomb consists of moving the prop latch from in front of the roller which is on the center pin of the force reducing toggle. The pressure of the release springs causes this toggle to collapse, and after an initial free motion, the hook-locking latch is struck a hammer blow and moved from in front of the hook roller. The hook then has no restraint and the weight of the bomb causes it to fall out of the rack from any position up to the vertical. To facilitate the action in the vertical position, the sides of the retaining lugs are sloped 15 degrees, which is the angle of 25 per cent friction, so that with no effective force to rock the bomb out of the rack, the slope would tend to let it slide out. This is added insurance to make an effective 15 degree slope of the rack when it is actually vertical. Since the bomb weight is not used to open the release mechanism, the manner of its application has no effect on the release action. The smoothness of the hook surface is therefore immaterial, and any indentation due to softness or brinelling as a result of vibration has no effect on the operation. The spring required to trip the bomb produces about 25 times the amount of energy necessary to overcome the friction at the roller caused by the weight of the bomb and to effect release.

To improve operation of the arming mechanism, the coils are made to occupy the maximum available space in order to have the greatest amount of copper and largest radiation area. The iron magnet frame consists of a single rectangular block with two cavities machined in it. It fits snugly between the side walls of the rack to which it is bolted and pinned, giving the best heat transfer and the maximum rigidity of the rack during loading. To obtain enough force for the arming, the size of the coil permits the use of No. 33 Wire, Roevar insulated, without excessive temperature rise and with sufficient force developed to give approximately twice the force of the original rack at no greater consumption of current.

The Mark 51 Mod 0 rack was expected to perform satisfactorily because of (1) greater facility in attaching bombs, (2) greater reliability in release of bombs because of a release mechanism which does not depend on bomb weight for source of energy, impact action of release springs, and impact action of release coil, (3) reduction of corrosion by use of stainless steel, (4) provision of a safety factor of 5 for all loads, (5) use of dead center type latches, and (6) more positive arming action because of the use of pivoted parts and an improved coil.[11] In preliminary trials these expectations appear to have been met.

18.5 AUTOMATIC THREAD GAGES

Summary

A new type of thread gage has been developed for production use. Production models tested in service have given up to a 10-fold increase in speed and a 300-fold increase in life, and have handled as many as 300,000 pieces with the original gage parts and without excessive loss of discrimination.

A bibliography on the manufacture and gaging of threads and a monograph on the manufacture of thread rings and plug gages have been prepared.

As a result of this work and its applications in industry, a substantial contribution was made to the art of gaging threads as well as a considerable speed-up in the large-scale production of needed war materials.

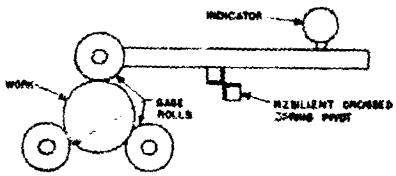

FIGURE 5. Schematic arrangement of roller type thread gage.

FIGURE [illegible]. Test model of roller type thread gage.

18.5.1 The Problem

In April 1942, a serious limitation in the production of war materials was resulting from a shortage of thread gages and especially from a shortage of ring gages. Because of their design and the precision required in their manufacture, mass production was practically impossible. The limited number of gages produced by tool room methods was unable to cope with the daily production of hundreds of millions of threaded parts requiring inspection. The situation was made even more acute by the fact that the available type of gage could be used on only a few thousand pieces before its wear became excessive and it had to be discarded.

At the request of the U. S. Army Ordnance Department, a project was established to find an immediate, practical solution to this problem.[e] Suggestions included (1) the modification of current designs to permit easy salvage, (2) the development of mass production methods for the current designs, (3) the perfection of special treatments to protect the surfaces of current gages from wear, and (4) the development of an entirely new type of gage which could be mass-produced or which would contain easily replaceable wearing elements or be highly resistant to wear.

Before this investigation was completed, the Ordnance Department undertook to provide temporary relief for the gage shortage by giving contracts for gage manufacture to small tool shops. It was found, however, that few such shops knew the techniques of thread gage production and that no adequate information was readily available. Accordingly, a simple thread gage production manual was requested for use by the personnel of these shops.[f]

Finally, since no bibliography on thread manufacture and gaging had been published since 1918, a request was made for the preparation and publication of an up-to-date bibliography.[g]

18.5.2 Procedure

The suggested modification of current designs to permit easy salvage was discarded with the decision

[e] This investigation was conducted by the Bryant Chucking Grinder Company, Springfield, Vermont, as subcontractor to the Jones and Lamson Machine Company, Springfield, Vermont, under OSRD contract OEMsr-102 as Project OD-10.

[f] Preparation of this manual was undertaken by the Jones and Lamson Machine Company, Springfield, Vermont.

[g] Preparation of this bibliography was undertaken by the Jones and Lamson Machine Company, Springfield, Vermont.

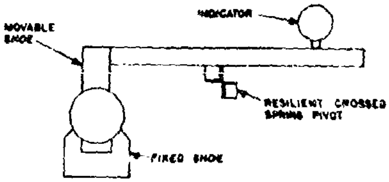

Figure 5. Schematic arrangement of shoe-type gage for external threads.

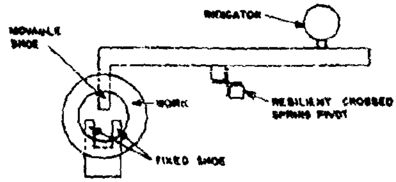

Figure 6. Schematic arrangement of shoe-type gage for internal threads.

that the only practical modifications would involve the use of replaceable wearing elements or the plating and refinishing of worn gages, either of which would involve time-consuming precision methods.

Preliminary considerations showed that no radical improvement could be expected by developing mass production methods for the current design of gages. The manufacture of plug thread gages had already been facilitated by the adoption of the thread grinder, but this development was proceeding as rapidly as could be expected and no other production method appeared to offer much promise.

Investigation revealed a number of potentially useful methods for the treatment of gage parts to increase wear resistance. The only one offering considerable improvement, however, seemed to be the application of a thin, uniform layer of tungsten or other hard carbide, and no useful method was available for the application of such a layer to the surface of a finished gage.

Major emphasis was therefore placed on the development of a new type of gage. Here it was recognized immediately that if a thread is to be gaged throughout its length, as is necessary to insure assembly, the gage must be turned on the thread a number of turns equal to the number of threads. The successive threads of the gage are consequently subjected to wearing action in proportion to their distance from the back end of the gage, since each succeeding thread is subject to wear over fewer turns. This results in the tapered or "bell mouthed" wear commonly noted in used ring thread gages.

This bell-mouthed wear could be eliminated if the part could be introduced without threading on and gaged by only a slight amount of turning needed to insure seating and to gage the full circumference. This would require only a fractional turn for each gaging, reducing the total wear on the gage elements and prolonging the life of the device.

On this basis, consideration was given first to a design incorporating two threaded rollers mounted on fixed parallel axes and one roller on a movable axis parallel to the other two (Figure 3). The movable roller is mounted at the end of a pivoted arm with the pivot axis parallel to the roller axis, the three rollers being approximately equally spaced angularly about the axis of the work or piece to be gaged. A dial indicator bears on the pivoted arm to indicate its position and thereby the deviation in the size of the work. In operation, the movable roller is lifted away from the fixed rollers and the work introduced between them. Then the arm is released, the movable roller bears down upon the work, pressing it against the fixed rollers, and the dial indicator bears against the arm. The dial indicator zero setting is established by inserting a master reference workpiece.

A test model constructed to this design (Figure 4) was found to possess several undesirable features. With threaded rollers, the phasing of the rollers to insure simultaneous seating requires an excessively complex mechanism. If simple grooved rollers are used, they must be skewed to match the lead angle of the thread; furthermore, to insure proper engagement, the rollers must be so short that they cannot gage the entire length of thread in one setting. In addition, there is no wiping action to remove the dirt which accumulates on the surface during the gaging of dirty or oily parts, and the gaging is not uniformly accurate.

From these observations it was decided that some sliding contact must be provided, both to remove dirt and to avoid mechanical problems introduced by the rollers. The gage was therefore modified by replacing the three rollers with three threaded shoes which have relatively narrow bearing faces and sharp corners to scrape away dirt and which are long enough to engage the full length of the thread being gaged. The method of gaging by dial indicator bearing on a movable gage

[redacted]

element was retained. The flat spring pivot was adopted as the best means available for providing a frictionless, accurately fixed pivot for limited motion. Two arrangements of this design were planned for external and internal threads (Figures 5 and 6).

At the suggestion of the Ordnance Department, experimental models were constructed for both male and female threads of the 2-inch-12NS-1 thread on a component of the M-21 booster (Figure 7).

FIGURE 7. Gaging element of male-thread gage.

In order to make the operation of the gage as nearly automatic as possible and to reduce the labor of thread gaging, the design was again modified to provide a movable element which is held open by a spring and closed by a solenoid. A microswitch controls the solenoid and is actuated by a small pin between the fixed shoes. When a workpiece is pressed against the fixed shoes, it engages the pin, closes the microswitch, and thus operates the solenoid to close the gage. Moderate hand pressure against the workpiece to cock it slightly is sufficient to release the gage. This gage was later redesigned (Figure 8) to handle the windshield mounting thread on the hardened A.P. cap of the 40mm solid shot, and appeared to offer many distinct advantages; however, as a compromise on speed of operation for the sake of reliability, the automatic closing and opening feature was eliminated and the final gage for the A.P. cap was constructed for hand operation (Figure 9).

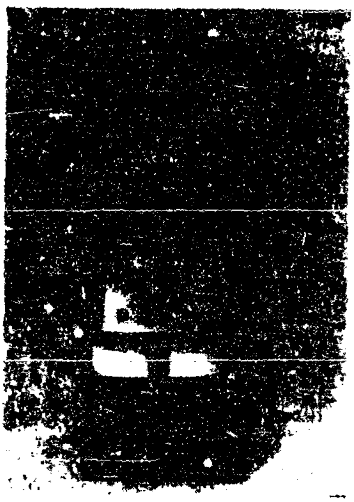

FIGURE 8. Assembled pilot model gage for female threads.

FIGURE 9. Pilot model of manually operated gage for male threads.

18.3.3 Results

The final model was sent into the field for service testing by manufacturers of Ordnance equipment on their production lines. In the hands of briefly trained, competent operators, it was found to be from five to ten times as fast as the conventional ring gage. Instead of screwing the workpiece into the gage, the operation consists of opening the gage by squeezing the lever, inserting the part, releasing the lever, and giving a half turn to seat and check roundness. The successive steps run one into the other in such a manner as to constitute what is substantially a single continuous operation.

When work began on this project, the life of a gage used on the AP cap, which is hardened after machining and not ground, was limited to the handling of about 1,000 pieces. On the same cap, the new gages handled 60,000 pieces without noticeable wear of gage parts, and some new gages still in service at the completion of this study have handled as many as 300,000 pieces with the original contacting elements. The discrimination of the new gages is sufficient to meet Ordnance Department requirements, and they reveal errors not caught with the standard design of ring gage.[10]

The bibliography[14] was compiled and 120 copies distributed, and the manual on gage manufacturing methods[1] was written and 500 copies distributed.

Later the designs were slightly modified for production models of the new gages, and by June 15, 1945, more than 1,200 units were manufactured and shipped. The production models included several sizes for manual operation (Figure 10) and one for electrical operation (Figure 11). Many of these production units have been used on several hundred thousand operations without noticeable wear and have greatly increased the speed and accuracy of inspection. In some cases they have made it possible to gage parts which could not be readily inspected by the older ring gages.

18.3.4 Conclusions

The new gage developed in this investigation was designed primarily as a Go gage for male threads to take the place of the conventional ring gage. Mating parts which pass this new gage will assemble with fits which are no tighter than was intended by the designer of the parts.

When gages wear rapidly, excessive allowances must be made for wear. As a consequence, parts checked during the early life of the gage fit together too loosely and parts gaged during its later life fit too tightly. The new gage, however, can be kept in continuous adjustment by resetting the dial indicator against a master plug inserted in the gage. Since the wear is slight, the thread form changes slowly and the

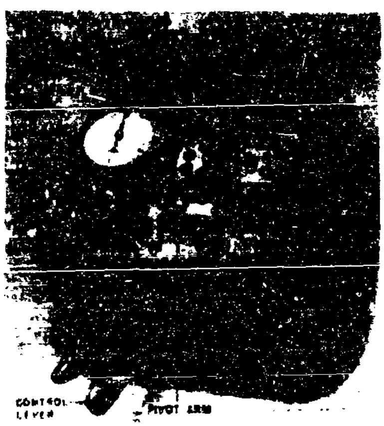

Figure 10. Production model of manually operated gage for male threads.

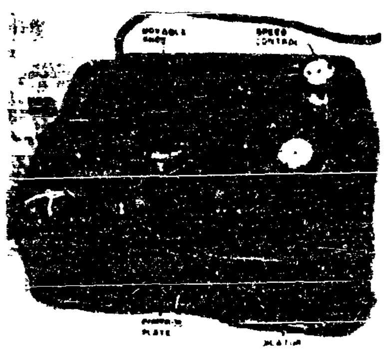

Figure 11. Production model of electrically operated gage for male threads.

gage can be reset many times without sacrifice of accuracy.

Not only does the new gage serve as a Go gage, but it also operates as a Not Go gage in checking pitch diameter. It will reject undersized parts where the thread form is reasonably true. Pitch errors are rejected by an oversize indication, provided the pitch diameter is not sufficiently undersize to produce a screw which can be assembled. Excessive and short pitch both show the same indication. The gage will not determine true minimum metal pitch diameter with some types of thread form, but in its use on Ordnance Department work it was required that occasional checks be made with truncated thread rings to insure complete control of minimum metal pitch diameter thread conditions.

The Go gage will not check thread form, but routine gaging with this type of gage accompanied by periodic checks of thread form with an optical, projection-type comparator for control of tooling will maintain all but the most extreme standards of high quality.

For many production purposes, thread form can be checked with sufficient accuracy by using two of the new gages, the second having relieved threads bearing at the pitch line only. This second gage serves the same purpose as the standard Not Go ring gage, an undersize indication being the basis for rejection.

Since the new gage is easily calibrated, extreme precision is not required in its production, and its design lends itself to mass production methods.

16.4 PNEUMATIC TIRE SUBSTITUTES[b]

Summary

Of the thousands of substitutes proposed to replace pneumatic automobile tires for civilian and military service, the twelve most promising were constructed and tested. Although none of these twelve had been found satisfactory when the project was terminated because of the assured success of the synthetic rubber program, one of them, the Martin Elastic Spoke tire appeared to deserve additional study. Several of the Martin tires had been run more than 7,500 miles and one more than 10,000 miles over paved and unpaved roads at speeds up to 85 mph.

16.4.1 The Problem

In March 1942, when the danger of a rubber shortage was becoming increasingly acute, the U. S. Army Quartermaster Corps and later the Ordnance Department asked for a thorough investigation of "the present development and patents covering devices that would eliminate the use of rubber tires, and recommendations as to possibilities of further development."[c]

This problem was one which had been given much thought and study, particularly during the last war and at times of high rubber prices, and thousands of patents and suggestions had been submitted for consideration. It appeared at the outset that the complete elimination of natural or synthetic rubber was impossible and that the goal should be the use of as little rubber as possible.

In the search for a tire or complete wheel which could be used on present automotive vehicles, maximum life, minimum use of critical material, and ease of manufacturing were considered of paramount importance. The static load deflection of the substitute tire was to approach that of the pneumatic. The total weight and particularly the wheel unsprung weight (that portion of the weight of the wheel lying between the springs of the wheel and the ground) were both to be kept to a minimum. The tread area in contact with the road was, if possible, to equal that of the pneumatic tire.

16.4.2 Procedure

Between March 1942 and October 1943, when work was discontinued, 12 wheels (5 non-resilient and 7 resilient) were built with both private and government funds and examined at Camp Holabird, Fort Knox, and other military establishments.[c] Those which ar-

[b] Project OD-96.

[c] This investigation was conducted by the Budd Wheel Company of Detroit, Mich., OSRD contract OEMsr-998; Kelsey-Hayes Wheel Company, Detroit, Mich., OEMsr-967; Motor Wheel Corporation, Lansing, Mich.; American Steel & Wire Company, Cleveland, Ohio, OEMsr-72; [illegible], Pittsburgh, Pa., OEMsr-[illegible]; Dr. Philip [illegible] of New York, N. Y., OEMsr-653; William Allen Brown of Philadelphia, Pa., OEMsr-[illegible]; James V. Martin of Rockville Park, N. J.; James Mathew Maclean of Smith and Spear, Detroit, Mich., OEMsr-757; William E. [illegible] of Houston, Tex., OEMsr-758; Factory Products Company of Dearborn, Mich., OEMsr-786; August Corporation, New York, N. Y., OEMsr-775, under supervision of Division 12, OSRD, and in coordination with the Resilient Wheel Committee, representing the U. S. Army and the wheel and tire industry.

FIGURE 12. Non-resilient substitute tires. Grason (upper left), Atlas Habberstadt (upper right), Knox (lower left), and Goodyear (lower right). The Budd is not shown here.

dicated any promise were placed on vehicles and run over paved road sections at different speeds, given cornering tests, and then run around test course until failure occurred. In the case of the Martin Elastic Spoke tire, additional laboratory tests were performed to determine some of its operating characteristics.[1]

Results

NON-RESILIENT SUBSTITUTES

Five possible substitutes (Figure 12) for a spare tire, all rigid and non-resilient, were investigated with the thought that, if the rubber shortage became extremely critical, something of this type might serve in an emergency in place of the normal fifth or spare tire.

The *Atlas Habberstadt* tire is a wooden rim mounted in place of the pneumatic; the *Budd* wheel is a pressed steel disk with a rubber tread member; the *Goodyear* tire is a Thiokol-impregnated cotton fabric tread material mounted in place of the regular pneumatic; the *Knox* tire uses a brake block material as a tread member in place of the pneumatic tire; and the *Grason* wheel is a thin disk designed to be placed outside the pneumatic tire and to carry the weight of the

[1] These tests were conducted by the Vibration Fatigue Laboratory of the American Steel & Wire Company, Cleveland, Ohio.

vehicle in case the pneumatic tire is damaged. Since they are rigid, these five types transfer all of the road shock to bearing and axle structures and other vehicle parts, and they can be used only for emergency purposes for very limited mileage and at low speed. All but the Grasso wheel were discarded without any mileage tests, for it was recognized that their life would be relatively short. The Grasso wheels failed at 20 miles on the test course, at moderate speeds.

RESILIENT SUBSTITUTES

Seven types of resilient substitutes (Figure 13) were tested and in some cases modified and retested where this was possible. Their general characteristics are given in Table 1.

In preliminary tests on the *Ampat* wheel, failure began within 10 miles. Modifications were attempted but did not significantly improve performance.

The *Beyer and Tarn* tire was exceptionally heavy, its unsprung weight very high, and it failed after some 50 miles of driving over paved roads and around the test course.

In early tests, the *Brown* tire[a] was reported by the inventor to survive approximately 500 miles of driving. After attempted improvement and simplification, however, it failed after some 300 miles.

The *Budd* tire showed considerable resiliency when used over paved roads at speeds less than 30 mph but failed under more severe tests at about 100 miles.

A car equipped with the *Joor* tire drove fairly well over the test course, but the tire failed within 30 miles.

The *MacLean* tire, similar in construction to many resilient streetcar wheels, failed after relatively low mileage, principally because the wheel had been constructed from castings which cracked. Had pressed disks similar to standard automotive wheels been used, it is believed more satisfactory results would have been obtained.

The *Marton Elastic Spoke* tire (Figure 14) appeared to be the most promising of all types tested. It uses the standard wheel with a portion of the rim cut off. Resiliency is obtained through a series of radial elastic spokes and three semiflexible hickory hoops comprising the tread rim. A rubber or synthetic tread cover is vulcanized and bonded to these hoops. Hickory pins connect the elastic spokes to both the wheel and the tread rim. The spokes are assembled prestressed in tension. The spokes at the portion of the wheel where the load is applied are partially relaxed or under compression, depending on the load or force applied, and

[a] Data on this tire are not available since its construction was not completed until after termination of work on the project.

TABLE 1. Comparative Characteristics of 6-Ply Pneumatic Tire and Proposed Resilient Substitutes

Tire	Weight in pounds (incl. wheel)	Wheel unsprung weight in pounds (approx.)	Resilient member	Tread	Static load deflection in inches 1,000 lb	Static load deflection in inches 2,000 lb
Pneumatic tire	65	Arbitrary	Air and rubber	Rubber	0.67	1.25*
Ampat Type A	87	68	Cantilever spring	Rubber	[illegible]	0.70
Ampat Type B	117	96	Cantilever leaf springs	Goodyear corrugated fabrics	0.30	[illegible]
Beyer and Tarn	155	198	Coiled spring annulus	Rubber	0.03	0.06
Brown—data not available						
Budd	122	52	Radial coiled springs	Rubber	0.65	
Joor	[illegible]	15	Steel strip S shaped	Rubber	0.20	0.35
MacLean 12 mm	108†	55	Rubber pads	Rubber	0.16	0.28
MacLean [illegible]	100†	55	Rubber pads	Rubber	0.30	0.70‡
Marton Type A	120	21	Steel leaf and coiled spring	Rubber	1.00	
Marton Type B	[illegible]	28	Helical leaf spring	Rubber	0.70	
Marton Type C	44	26	Rubber covered hickory hoops	Rubber	0.80	
Marton Elastic Spoke	38	23	Rubber spoke	Rubber	0.60	1.6

* 35 psi air pressure. At 90 psi deflections are 0.75 and 1.32, respectively.
† Based on aluminum construction. For steel, approximately 125 lb.
‡ This was maximum deflection available for this wheel.

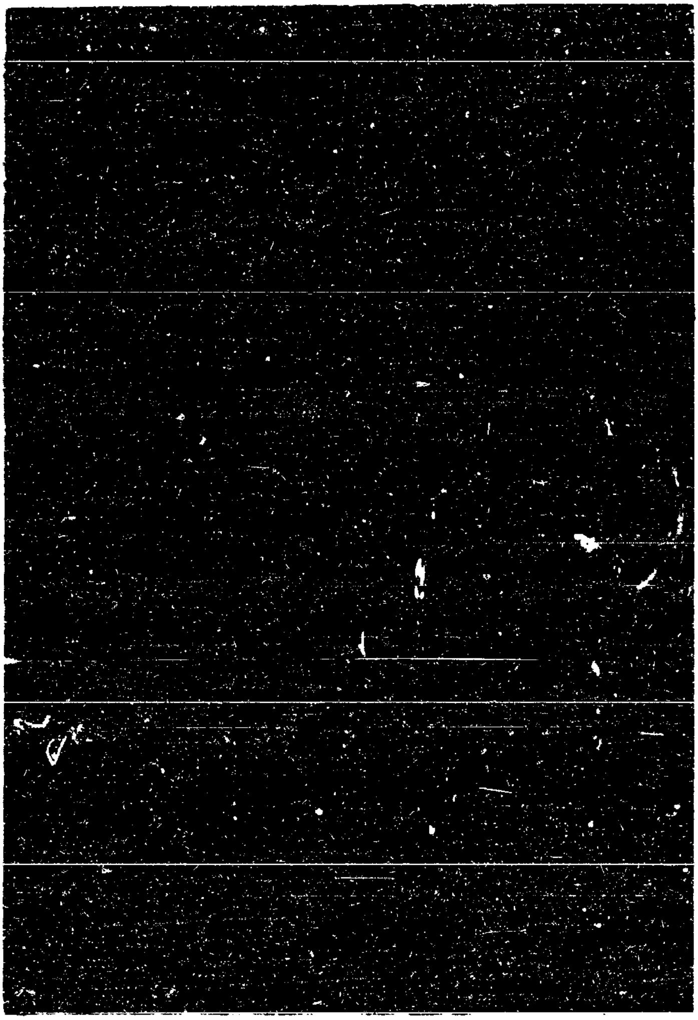

FIGURE 13. Resilient substitute tires. MacLean (top left); Brown (top right); Joo (middle left); Bevo and Larse (middle right); Budd (bottom left); and Ampat (bottom right).

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FIGURE 11. Army jeep equipped with Martin elastic spoke tires.

the load on the tire is distributed among approximately two thirds of the spokes. The static deflection closely approaches that of the pneumatic tire.

Three of these tires survived 7,500 miles without failure, and one was still serviceable after 10,000 miles (see Table 2). Tread wear measured on one of the tires showed a loss of about $\frac{1}{64}$ inch of rubber at

TABLE 2. Martin Elastic Spoke Tire Mileage.

Miles driven	Tires which failed	Tires still serviceable
0–100	6	
101–1,000	10	3
1,001–2,000	6	3
2,001–3,000	3	5
3,001–4,000	2	
4,001–5,000		
5,001–7,500		4
7,501–10,000	3	
10,001–15,000		1
	31	16

5,000 miles and about $\frac{1}{32}$ inch at 9,000. At slow speeds and over brick and gravel, the riding qualities were found to be less satisfactory than with pneumatic tires, but at speeds more than 30 miles per hour there is little noticeable difference. After 30 miles of driving at 70 mph, temperature in the center tread hoops was found to be only 12 degrees above atmospheric. The tires survived speeds up to 85 mph. Tires deliberately damaged by machine-gun fire continued to function, even with 50 per cent of the parts damaged and ineffective.

In order to reduce the amount of rubber in the tire, an investigation was conducted on the use of Neoprene in place of rubber in the spokes. It appeared that a Neoprene spoke could be used satisfactorily.[78] Three other modifications aimed at saving rubber (Martin Types A, B, and C) were constructed but not subjected to field tests before this project was terminated.

10.4.4 Conclusions

At the end of the project, none of the substitute tires or wheels was ready for complete and comprehensive tests. All except the Martin Wheel depend on some form of steel spring mechanism for their resiliency, and it appears from the limited tests conducted with them that if anything approaching adequate resiliency were to be obtained, their life would be very limited. Even when used primarily on paved roads and at reduced speed, they would probably not sur

vive one or two thousand miles. They are further handicapped by high weight, high unsprung weight, and failure to absorb damaging vibrations.

The Martin type tire was found in this study to be the most satisfactory and the one requiring the least developmental work before it could be put into limited production. Although it contains nearly as much rubber as does the pneumatic tire and thus does not conform strictly to the requirements, it is believed that this rubber can be successfully replaced by synthetic or other substitutes.

While no mechanical design is likely to possess *all* the advantages of a pneumatic tire, it is considered likely that a vigorous engineering program could produce an acceptable emergency substitute, perhaps based on the Martin, Ampat, Budd, or MacLean constructions.

18.5 EMERGENCY RESCUE EQUIPMENT

18.5.1 Seven-Man Sailing Boat[1]

Summary

A seven-man pneumatic life raft designed to be carried by aircraft has been developed and tested. One of its principal new features is that it is designed to be sailed. This feature is incorporated not so much to permit covering of distance as to reduce the likelihood of seasickness, both by easing the motion and by giving at least some of the crew something to do. Other features are great beam and high sides, together with small bulk made possible by a twin-tube construction which provides increased floor space, additional freeboard, and protection from wind. An inflatable double bottom protects occupants from the cold.

The new raft is believed to represent a decided improvement over existing models by providing maximum comfort for the crew, protection against sun and rain, camouflage protection against air attack, and small bulk in stowage. It can be sailed by inexperienced personnel.

The Problem

At the request of the Committee on Emergency Rescue Equipment of the Joint Chiefs of Staff and the U. S. Navy Coordinator of Research and Development, an investigation was undertaken in September 1943 on a new airborne pneumatic life raft.[m] The available type of raft, the Coordinator stated, was inadequate for the use intended. Specifications for the new type called for (1) maximum comfort for the crew, enabling them to live and sleep many days aboard the raft, (2) accommodations for the maximum number of persons and the maximum amount of emergency supplies and equipment for the least weight and size of the raft, (3) provisions for sailing, and (4) dimensions allowing it to fit into the space currently allocated aboard planes.

These requirements indicated that an entirely new raft design was necessary.

Procedure

Experiments were started with a standard Navy Mark VII raft to determine the best types of mast, rig, and lateral plane area. Pneumatic fabric leeboards were fastened to the raft tube and a fabric fin was placed on the bottom of the raft on its center line. The pneumatic leeboards were filled with water and supplemented with air from a hand pump. The fin was stiffened by two oar blades and was constructed so that it could be turned inside out and placed inside the raft during tests of the leeboards. An A-frame mast was mounted on the raft, set in two sockets *attached to the main tube*, and stays extended from a masthead Y fitting to the bow and stern. A single triangular sail was used.

Tests on this preliminary model showed that the leeboards offer considerable stability, but that the raft is sluggish to maneuver, uncomfortable for seven men, and requires too much space in proportion to its size. The leeboards were removed and a fin keel used. This provided considerable improvement in maneuverability.

Based upon the results of these early trials, a new type of raft was designed, and a double tube was adopted in place of the usual single tube in order to provide more usable floor area, greater freeboard, increased stability, and protection against spray, and to make possible a smaller main tube which could be used as a headrest. Instead of a double or A mast a single mast was used to simplify rigging and han

[1] Project NS-162

[m] This investigation was conducted by Sparkman & Stephens, Inc., New York, N. Y., in cooperation with the B. F. Goodrich Company, Akron, Ohio.

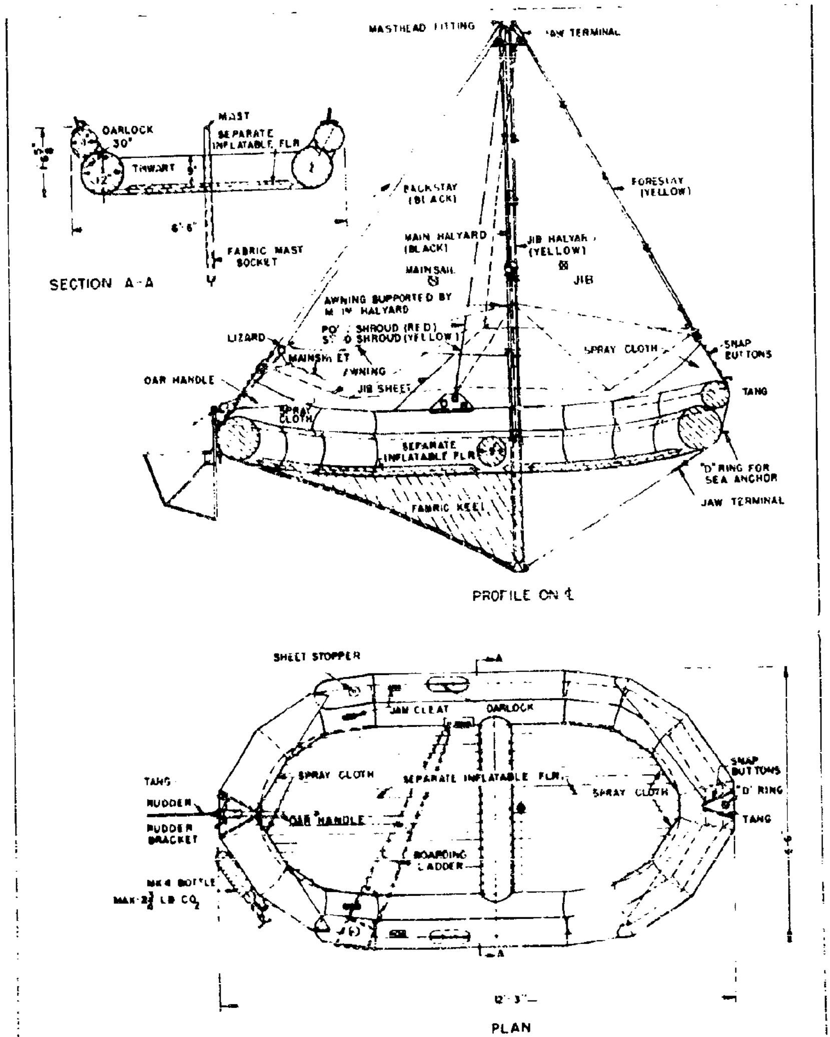

Figure 15. Construction of [illegible] pneumatic life raft

These could be constructed to inflate automatically with the main tube.

Corresponding colors are used for each sail and its raft attachments.

The complete raft, including rigging and all accessories, can be rolled to fit into a standard raft case 19 inches in diameter and 36 inches long. The raft alone, including the keel and inflatable floor, weighs 58½ pounds and provides a floor area of 31.6 square feet, in contrast to approximately 61 pounds and 14.6 square feet, respectively, for the Navy Mark VII raft.

CONCLUSIONS

The raft as finally built and given preliminary tests under both Army and Navy observation[22] appears to represent a decided improvement over existing types (Figure 18). All tests indicated that seven men can be adequately accommodated in safety and comfort. The inflatable double bottom definitely protects them from cold water temperatures. The twin tube feature provides increased comfort and protection. The combination awning, camouflage cover, and rain-catcher is waterproof and affords adequate protection against rain, snow, wind, sun, and night dampness, as well as a means of catching rain water for drinking, and offers some protection against enemy detection.

In moderate breezes, the raft can make progress to windward, although in strong or light breezes this would depend largely on the skill of the helmsman. Across the wind or downwind, the raft goes well. In general, the sail, centerboard, and rudder equipment give satisfactory control over the raft, so that if the crew want to stay in one position (the last known position is usually that at which survivors are most likely to be picked up), it is possible for them to do so.

The stability is satisfactory. If capsized, the raft can be righted by one man.

For complete evaluation, the new raft should be tested under actual sea conditions with typical bomber crews fully dressed in heavy flying clothing.

18.5.2 Airborne Lifeboat[a]

General specifications have been developed for a motor lifeboat which can accommodate seven to ten men and which can be carried on the underside of an airplane fuselage and dropped by parachute to men cast adrift from ditched planes.

For such a boat which could be carried by a plane similar to the B-17 Flying Fortress, it was recommended[b] that the lifeboat should weigh 3,000 pounds, the hull alone (including slings and buoyancy chambers) weighing between 800 and 900 pounds. The motor should be similar to the Austin Marine, with a weight of 210 pounds plus 30 pounds for miscellaneous items.

Two parachutes would be required, each 96 feet in diameter and together weighing 500 pounds.

The center of gravity of the lifeboat should be forward of the midship section, and, when slung into position on the plane, should be at the center of gravity of the plane. The bow of the lifeboat should not be too far forward, since otherwise there would be a possibility of the boat's scraping the bottom of the plane fuselage when released.

Provisions and supplies should be included for ten men and enough gasoline supplied for approximately 400 miles of operation.

When it was learned that the Army Air Forces were independently designing their own airborne lifeboat, this project was discontinued and no test model was constructed.[23]

FIGURE 18. Seven-man raft under way in calm sea.

[a] Project NS-101.

[b] This investigation was conducted by Sparkman & Stephens, Inc., New York, N. Y., under OSRD contract OEMsr-151.

18.6 RAIN-REPELLENT COATINGS[b]

Summary

A group of new rain-repellent coatings has been developed to improve visibility through rain-covered windshields. Although none of these films provides prolonged protection, some are effective for periods up to 300 minutes in conditions simulating moderate to heavy rainfall.

In some cases, these coatings may be renewed by rubbing even after they have apparently lost their activity. Of special significance are forms devised to permit application during rain.

In the course of this study, the properties of more than 50 substances were investigated, all of them prepared in mixtures with wax as the essential rain-repellent ingredient. They include various soaps, organo-tin compounds, nitrogenous bases, silicones, plastics, lacquers, and commercial rain-repellent products. The most promising combinations appear to be zinc palmitate and wax; tri-octyl silicone and wax; tetra-octyl tin and wax; shellac and wax; and zinc palmitate, wax, and isoquinoline.

18.6.1 The Problem

The impairment of visibility produced by rain or spray on a windshield or other optical surface has particular significance in military operations, especially with aircraft and with special sighting instruments which cannot be equipped with mechanical windshield wipers.

In order to control this blinding effect, chemicals were needed to provide an effective rain-repellent film or coating to be applied to the exposed surface. To be most useful, such a coating must be easy to prepare and apply, hard enough to withstand normal handling, free from undesirable optical effects, and able to remain effective after long exposure to rain.

Two broad classes of vision surfaces were considered: those of glass and those of transparent plastics. When rain strikes either type, the phenomena are much the same. If the surface is scrupulously clean, the water will spread (the angle of contact between glass, water, and air being zero degrees in magnitude) and tend to drain as a continuous sheet or film of water. A surface which has been exposed to the atmosphere for some time, however, is usually not clean and usually not completely wetted by water. When rain falls on an inclined surface of this sort, the water settles as flat, irregular drops, drainage takes place along twisting paths or channels, and these relatively massive bodies of water cause obstruction and distortion of vision.

One method to improve vision is to modify the surface with a *wetting agent* which would lower the surface tension and spread the water in a thin, uniform, transparent film. Since wetting agents by definition are soluble in water, any coating made with such substances would be quickly dissolved and removed.

A more practical method is to modify the surface with a *water-repellent* coating which would give a large angle of contact between coating, water, and air, and cause the water to be shed in discrete droplets so small that they would not interfere with vision.

As a water repellent, no compound was readily available to equal paraffin wax in giving a high contact angle between coating, water, and air, and a low solubility in rain. Thus, it appeared at the outset that a paraffin wax coating possesses at least some of the required characteristics, but unfortunately it has by itself little or no affinity for glass. An investigation was therefore initiated by NDRC to find materials which, in one way or another, can give a firm adhesive bond between glass and a wax coating.[c]

18.6.2 Procedure

MATERIALS

A number of *paraffin waxes* were studied, with the most suitable being a semimicro crystalline wax melting at 52 C. Others, with melting points from 62 to 67 C, were found less satisfactory.

As mixing materials which themselves possessed at least some degree of water repellency and of affinity for glass, various *soaps* were prepared and tested.[d] In the absence of wax, none of them is easily applied to glass. A series of paste-like mixtures was then made, each composed of paraffin wax, one of

[b] Project AC-39.

[c] This investigation was conducted by the National Research Corporation, Boston, Mass., under OSRD contract OEMsr-136.

[d] Aluminum stearate, calcium stearate, cobalt stearate, ferric stearate, lead stearate, zinc stearate, aluminum palmitate, cobalt palmitate, zinc palmitate, aluminum resinate, cobalt resinate, lead resinate, zinc resinate, aluminum oleate, copper oleate, lead oleate, lead naphthenate, and zinc naphthenate.

these soaps, and a suitable solvent, and of these, a *zinc palmitate* mixture was selected as the most suitable for further tests.

It was felt that certain organo-metallic compounds might have value, and several *tetra alkyl tin compounds* were selected because of their relatively low toxicity and flammability.[a] Tetra-ethyl tin, tetra octyl tin, and tetra acetyl tin appeared to be most promising and were studied in more detail.

Nitrogenous bases had been recommended, and several of these were prepared.[b] Without wax, none of these can be applied satisfactorily to glass surfaces, and even with wax only two appeared to be useful. Meso methyl tetra methyl benzimidazole gives a film which can be applied to glass, but since this material is not readily available and since it gives a film no better than others obtained more easily, it was not considered further. Isoquinoline was studied in special mixtures with *zinc palmitate* and wax to give rain-repellent coatings which can be applied to wet surfaces.

Twelve different *silicone* mixtures were synthesized, giving a series of films with properties depending upon the predominant monomer in each product and upon the temperature at which it is prepared.[c] When applied directly to glass, all of these materials give films which are extremely perishable; they repel rain for only a few moments and then flood completely. When mixed with wax, however, nine of the silicones give more permanent films, and these compounds (the ethyl, amyl, tri-amyl, tri-octyl, tri decyl, phenyl, di phenyl, tri phenyl, and tetra phenyl silicones) were investigated further.

Finally, investigations were conducted on a number of commercially available plastics[d] and a commercial rain-repellent compound, the Carr Rain Repeller, which is apparently a quick drying lacquer substance containing wax. None of the plastics appeared to be useful directly, giving either highly perishable films when used alone or marked by poor optical qualities when mixed with wax, and all were discarded except Plexiglas and several "Vinylites" which were used in special applications.

Application

The compounds selected above were applied in one of two forms to give a repellent coating: (1) mixed with wax and, if necessary, a suitable solvent, and applied directly to the surface; (2) polymerized or deposited from a solution on the surface, alone or with wax, and baked if necessary to give a subcoat to which paraffin wax was applied later as a top coat.

In addition, special combinations of *zinc palmitate*, wax, and isoquinoline were prepared in benzene and carbon tetrachloride for use on wet glass, and were applied by spray gun.

Tests

Preliminary measurements were made of the contact angle between each coating, air, and water, and of the tilt angle, or angle at which surfaces must be tilted for drops of certain sizes to roll off them.

TABLE 8. Durability Tests on Wax Mixture Coatings

(Each compound listed here was applied in a mixture with paraffin wax and exposed in a rain machine.)

Compound	Surface coated	Rain (inches per hr)	Wind (mph)	First sign of distortion (minutes)	Start of flood (min)
Zinc palmitate	Glass	25	12-20	28	55
Zinc palmitate	Plexiglas	25	12-20	30	85
Tetra ethyl tin	Glass	25	12-20	40	55
Tetra acetyl tin	Glass	25	12-20	40	55
Tetra octyl tin	Glass	25	12-20	60	85
Ethyl silicone	Glass	25	12-20	25	90
Tri amyl silicone	Glass	25	12-20	85	
Tri decyl silicone	Glass	25	12-20	5	115
Tetra phenyl silicone	Glass	25	12-20	15	75
"Vinylite" copolymer	Glass	25	12-20	6	8
Shellac	Glass	25	12-20	0	

The ability of the different coatings to withstand rain was measured in rain machines which could give any desired degree of rainfall at any desired wind velocity. In most cases, records were made of the times when each coating first showed distortion of the drops on its surface, when flooding began, and when vision was definitely interrupted.

[a] Tetra ethyl tin, tetra isoamyl tin, tetra octyl tin, tetra acetyl tin, tetra ethyl tin chloride, and tetra ethyl tin fluoride.

[b] Cation amine hydrochloride, tri methyl benzyl ammonium stearate, stearyl tri methyl ammonium bromide, lauryl pyridinium chloride, isoquinoline, and meso methyl tetra methyl benzimidazole.

[c] Ethyl silicone, di ethyl silicone, amyl silicone, tri amyl silicone, di octyl silicone, tri octyl silicone, tri decyl silicone, phenyl silicone, di phenyl silicone, tri phenyl silicone, tetra phenyl silicone, and tri naphthyl silicone.

[d] Monomeric methyl methacrylate, Lucite, Plexiglas, "Bondable Lucite," cellulose acetate, polystyrene, polyethylene, and various "Vinylites."

…e of these isoquinoline preparations may be applied with a pressure spray gun to a wet surface, whereupon it flows out in a thin, quick-drying film which, without rubbing, becomes perfectly clear and highly repellent, remaining active under 25 inches of rain per hour for more than 10 minutes. Successive coatings may be applied. The film may be completely removed by spraying lightly with carbon tetrachloride.

18.6.4 Conclusions

The best new combinations developed during this research are zinc palmitate and wax (*Anti-Rain Compound, Experimental Type 2-A*); shellac and wax, applied as a subcoat and then covered with a wax top coat (*Anti-Rain Compound, Experimental Type 2-C*); zinc palmitate, wax, isoquinoline, benzene, and carbon tetrachloride (*Anti-Rain Compound, Experimental Types 2-D and 2-E*), applied to wet surfaces; tetra octyl tin and wax; and tri octyl silicone, applied as a subcoat and then covered with a wax coat. Although these may be surpassed in durability by other compounds, they possess the best combination of availability, ease of application, ease of renewal, and durability.[39]

None of the materials tested or developed in this study possesses any permanent value. It is significant, however, that occasional light wiping across a surface coated with these compounds will prolong the useful life of the coating, perhaps to as much as 8 hours. It is felt that a windshield wiper might be profitably used in conjunction with such coatings.

The action of quinoline is apparently due to its ability to displace the film of water and carry the wax and zinc palmitate to the glass surface, where they are precipitated in place. A lower concentration of quinoline (*Type 2-D*) appears to be most useful for application to stationary objects, while mixtures with higher concentration (*Type 2-E*) may be useful for application to the windshields of airplanes while in flight through rain.

It appears that the development of a permanently rain-repellent surface is remote, but useful temporary coatings may be devised for aircraft. It does not appear that coatings with higher angle of contact will be readily found.

18.6.5 Recommendations

Jet systems to spray films of rain-repellent materials over the windshield should be developed particularly for airplanes. Further investigations are indicated, particularly on zinc palmitate-wax systems. Testing by military air services and commercial air lines in cooperation with a competent jet manufacturer should solve the problem of vision through an airplane windshield during a heavy rain storm.

18.7 ANTI-FOGGING METHODS

Summary

Anti-fogging compounds incorporating wetting agents as the active ingredients have been developed and found effective in improving the quality of vision through transparent surfaces. Their beneficial effect, however, is only temporary.

The fogging of some optical instruments, such as the Mark III 7 telescopic sight in use by naval dive bombers in 1942, can be avoided by the use of desiccating devices.

The most satisfactory way to prevent fogging of windshields is the use of internal heaters and defrosters.

18.7.1 The Problem

A common cause of impairment of visibility through vision devices is the fogging or misting which occurs when moisture condenses on the vision surfaces as very small, discrete droplets of water which refract the light rays coming through the surface and give a frosted appearance on the surface of the glass. This phenomenon occurs on the windshields of aircraft, water craft, and land vehicles, and on the lens elements of goggles, telescopes, periscopes, and similar devices, and in some circumstances may be severe enough to make an instrument practically opaque and useless.

A need for some means to control this fogging had been expressed particularly by the pilots of Navy dive bombers in the Southwest Pacific, who found their telescopic sights becoming heavily fogged during diving operations, and by representatives of the U. S. Army Tank Automotive Center, Detroit. With the belief that no single method would be generally applicable to all conditions of fogging, a study was begun on three possible methods: (1) the application of a wetting agent which would cause the moisture to spread over the surface in a thin uniform film offering only slight impairment to vision, (2) the application of a moisture absorbing coating, and (3)

the use of a device to desiccate the atmosphere surrounding the vision surface.*

The effectiveness of commercial anti-fogging products already on the market was also investigated.

Wetting Agents

Twenty-one wetting agents (see Table 5) were tested to determine their effectiveness by applying each to a glass surface which was then cooled below the dewpoint of air, dried, cooled again, and so on. The number of such fogging cycles through which a single application of a wetting agent would maintain visibility was taken as a measure of its effectiveness.

Most of these wetting agents were found to be effective on only the first fogging cycle, but six of them — Aerosol 18, Aerosol OT 100%, Alkanol B, Alkanol WXN, DuPont 189 S, and Igepon T Gel — gave distinctly better results. In order to develop a compound which could be applied quickly, easily, and effectively by relatively unskilled personnel,

Table 5. Wetting Agents

Trade name	Manufacturer
Aerosol OS	American Cyanamid & Chemical Corp.
Aerosol 18	American Cyanamid & Chemical Corp.
Aerosol OT 100%	American Cyanamid & Chemical Corp.
Aerosol OT — Calcium salt of	American Cyanamid & Chemical Corp.
Aerosol OT — Zinc salt of	American Cyanamid & Chemical Corp.
Alkanol B	E. I. DuPont deNemours and Company
Alkanol WXN	E. I. DuPont deNemours and Company
Amine 220	Carbide and Carbon Corporation
Deloamine ??	Carbide and Carbon Corporation
Duponol ME	E. I. DuPont deNemours and Company
Dupont MP 189S	E. I. DuPont deNemours and Company
Icepol CEA	General Dyestuff Corporation
Igepon AP Extra	General Dyestuff Corporation
Igepon T Gel	General Dyestuff Corporation
Tergitol Penetrant 4	Carbide and Carbon Corporation
Tergitol Penetrant 7	Carbide and Carbon Corporation
Tergitol Penetrant 7 plus triethanolamine	Carbide and Carbon Corporation
Tergitol Penetrant MEA	Carbide and Carbon Corporation
Wetting Agent 521	Commercial Solvents Corporation
Wetting Agent 56 B	Victor Chemical Works
Wetting Agent 56 D	Victor Chemical Works

solutions of these agents in volatile solvents were then prepared and tested. The most promising appeared to be a 5 per cent solution of Aerosol OT 100% in carbon tetrachloride, which is listed as *Anti-Fog Compound, Experimental Type I-A*, and which can be applied either by spraying or by rubbing with a moistened cloth. The film of wetting agent remaining on the glass is buffed lightly with a clean soft cloth until the surface is clean.

Field tests of *Type I-A* were conducted by the U.S. Navy Carrier Command at Pearl Harbor, with the material applied to the lens elements of telescopic sights, portions of the windshields, and instrument dial glasses of two planes which then were dived from an altitude of 20,000 feet and leveled off at 1,000 feet above sea level. The results were compared with untreated surfaces exposed to the same conditions.

To meet a demand for an anti-fogging compound in paste form, Aerosol OT 100% was combined with bentonite, precipitated calcium carbonate, alcohol, and water to give *Anti-fog Compound, Experimental Type I-C*. In addition, Aerosol OT 100% was combined with "Carbowax 1000" and glycerine to give an anti-fogging compound in the form of a solid stick.

Commercial Anti-Fogging Compounds

Thirteen compounds on the market as anti-fogging preparations were also investigated (see Table 6). Of these, some are effective over only a short period, a few possess more lasting activity, while the two best appeared to be Antimist and Cellosize WS Solution. These two were tested for their resistance to repeated fogging cycles.

Lacquer Wetting Agent Coating

Since it had been found early in this investigation that the durability of even the best wetting agent compositions is quite limited and that frequent reapplication is necessary, attempts were made to find some method of prolonging their effectiveness. This problem resolved essentially in seeking a method that would keep the wetting agent on the surface. It was reasoned that, if the wetting agent could be incorporated in a lacquer type coating, a higher concentration of wetting agent could be deposited on the surface and, at the same time, the rate of solution of the wetting agent would be retarded.

Since it is more compatible with organic solvents than are the other wetting agents available, Aerosol OT 100% was tested in combination with a number

* A fourth possible method, heating the vision surfaces so that their surface temperature is always higher than the dewpoint temperature of the surrounding atmosphere, was not investigated since it was already being studied by other workers.

of resins and lacquers. Preliminary experiments showed that the most satisfactory combination was one incorporating Aerosol with a waterspar lacquer (cellulose nitrate base), ethyl acetate, and butyl acetate. Coatings made from this material were then tested for ability to withstand repeated fogging cycles and for their solubility when completely immersed in water.

WATER-ABSORBENT FILMS

The possibility of preparing coatings which would prevent fogging of vision surfaces by absorbing any condensed moisture was studied in an effort to develop a film which would possess not only good optical quality and resistance to injury by normal wear, but also the property of regeneration, that is, the ability to absorb moisture when condensation occurs and to dispel it when the film is returned to conditions of normal humidity and temperature. After a search of the literature and a number of preliminary experiments, it was decided that the most promising material is a gelatin film containing glycerin-water solutions as dispersion media. Films in which the dispersion medium is dilute with respect to glycerin lose water to the atmosphere until an equilibrium is reached at the point where the partial pressure of the water in the atmosphere reaches the value of the partial pressure of water in the glycerin-water solution.

Experimental gelatin-glycerin-water films were therefore prepared and tested for resistance to repeated fogging cycles and normal handling. Attempts were also made to produce hard and highly resistant films by treating the gels with formaldehyde and with potassium dichromate.

Special attention was given to a moisture-absorbing film developed by William C. Geer, Ithaca, New York.

DESICCATING DEVICES

With some optical instruments, internal fogging may be prevented by drying the air surrounding the inner surfaces and then sealing the instruments completely. Often, however, the construction of the instruments makes it extremely difficult to create a permanent airtight seal, and in some cases such a seal used on aircraft with changing atmospheric pressure may strain and damage the instrument.

An alternate method was consequently developed for the Mark III 7 telescopic sight provided by the U. S. Navy Bureau of Ordnance. This sight was first completely overhauled and reassembled, all external glass-metal and metal-metal joints were sealed with rubber cement, and only the objective vent hole was left open. To this hole was fitted a drying tube filled

Table 6. Commercial Anti-Fogging Compounds.

Trade name	Manufacturer
A. F. C. 11	Continental Laboratories
Antiblurd	American-European Chemical Co.
Antifog lens stick	American Optical Co.
Antimist	Welmont Manufacturing Corporation
Cellosize WS solution for anti-fogging films	Carbide and Carbon Chemicals Corp.
Fogpruf (paste and liquid)	Mine Safety Appliances Co.
Kleer Vue	Scientific Cleansing Products Corp.
Mystic	American Products Company
No-fog cloth	Solvside Laboratories
No Mist	Scientific Cleansing Products Corp.
Savage No Mist	Savage Products Co.
Trident	Trident Manufacturing Company
Trident #2	Trident Manufacturing Company

with silica gel* and equipped at the outer end with a two-way valve designed to open in either direction under a small pressure differential. After final assembly, the sight was tested by being subjected to a temperature of 20 C for 20 minutes and then placed suddenly in an atmosphere at a temperature of 26 C and a relative humidity of 70 per cent.

18.7.2 Results

WETTING AGENTS

In the tests on Anti-Fogging Compound, Experimental Type A, no fogging occurred on the treated surfaces when the planes were dived from an altitude of 20,000 feet to 1,000 feet above sea level. In comparison, similar untreated surfaces were found to fog when the planes were dived to approximately 7,000 feet. The coating on the sights retained their efficiency while the planes were flown twice a day for a week. The coated windshields were occasionally rubbed with a clean dry cloth to remove dust, but otherwise were in good condition at the end of the week. Anti-Fogging Compound, Experimental Type 3-C, prepared as a paste, gave similar results.

COMMERCIAL ANTI-FOGGING COMPOUNDS

Of the commercial compounds tested, Cellosize WS Solution was found to be as effective as the new experimental types developed.

* No. 22 Silica Gel Dryer, manufactured by the Weatherhead Company, Cleveland, Ohio.

Lacquer Wetting Agent Coatings

Coatings made from Aerosol OT 100%, waterspar lacquer, ethyl acetate, and butyl acetate maintained good visibility over 14 fogging cycles. Soaking the films in water for more than 1 hour failed to strip them from glass. In contrast, other lacquer coatings tested were stripped completely from glass after soaking for only a few minutes.

These coatings unfortunately possess definite disadvantages. They are soft as compared with glass, and tend to pick up dust and dirt which cannot be removed without injuring the films. The coatings may be removed and renewed when they have lost their effectiveness, but this is a rather troublesome procedure. The optical quality of the films is only fair, but might be improved by further studies of application methods. In spite of the advantages possessed by the best of these films, their disadvantages were found to be sufficiently serious to warrant termination of this phase of the research.

Water-Absorbent Films

In fogging cycle tests, the gelatin-glycerin-water films withstood a considerable number of cycles, but they were found not hard enough to withstand normal handling without injury to the surfaces, and their optical quality left much to be desired. Attempts to harden these films by chemical treatment were not successful. For these reasons further work on this approach to the problem was discontinued.

The Geer moisture-absorbing film was found to be capable of preventing fog, but it, too, is not hard enough for practical application.

Air Desiccation Devices

The silica gel drying tube applied to the Mark III 7 telescopic sight was found to keep the optical surfaces perfectly clear when the sight was chilled and then plunged into warm, moist air. Similar sights not equipped with the drying tube were completely fogged under this treatment.

10.7.5 Conclusions

The methods, materials, and devices developed in this research require further field testing and development. In particular, the use of desiccating tubes such as the one applied to the Mark III 7 telescopic sight warrants additional study. Drier assemblies are generally applicable to other optical instruments,

Figure 20. Sine-disk propeller installed on Navy plane personnel boat.

double windshields, and similar vision devices which are subjected to large pressure changes, and seem to offer the most satisfactory and positive method to prevent fogging of such devices. The style, size, and location of the drier would have to be studied for each particular instrument. The drying tubes may be made of transparent plastic and filled with drying agents impregnated with indicator dyes which indicate by a color when the drying agent requires renewal.

10.8 SINE-DISK PROPELLERS[a]

Summary

A sine-disk propeller was investigated during the spring and summer of 1944 for use on a shallow-draft boat. Under the conditions of the tests, the device gave a maximum speed of only about 15 mph marked by considerable cavitation and vibration. It was expected that better hull design and engine-to-propeller gear ratios would give improved performance.

The design of the new propeller permits operation in shallow water considerably fouled with marine growths.

10.8.1 The Problem

A sine-disk propeller, consisting of an opposed pair of partially immersed wobble or sine-disk elements mounted on a transverse shaft immediately

[a] Project NS-166.

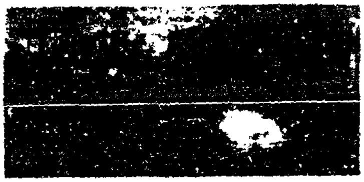

FIGURE 21. Navy plane personnel boat equipped with sine disk propeller under way at about 15 mph.

abaft a transom, had been proposed by its inventor[a] for use in shallow draft operations. In 1943 an investigation was initiated to determine the mechanical feasibility, practicability, and relative efficiency of the device.[aa]

16.8.2 Procedure

The sine disk propeller (Figure 20) was installed on a U. S. Navy Mark II Plane Personnel Boat powered with a 6-cylinder, 115 bhp engine. With screw propulsion, its top speed ranges from 24 to 30 mph. In order to accommodate the new propeller, the engine was placed in the stern abaft a plywood bulkhead, and the fuel tank was moved just abaft the forward cockpit. The after deck was extended forward to the bulkhead, and a suitable hatchway and covers were fitted on.

The propeller itself was designed with three possible longitudinal positions for the transverse shaft; a vertical or height adjustment through a considerable range; two breadth dimensions; a series of three gear sets which, with an interposed engine gearbox, provided six engine to propeller ratios, and a wide range of both flat and warped disks of varying angles, diameters, and peripheral shapes. To determine the effect of increased segment dimensions at small diameters, a series of multiple segment rotors was provided in four angle and axial length combinations. Several built-up plywood shrouds and housings were constructed for a study of the effect of baffling and shrouding.

With this equipment, trials were run on the Saginaw River and in Saginaw Bay during the spring and summer of 1944, and observations were made on a large number of trial assembly combinations (Figure 21). Special runs were made in weed-choked waters, over shoals and obstructions, through flotsam, and on beaches. As an added experiment, towing tests were made with the boat accelerated by means of a towline to a speed above the stern eddy range, when the line was cast off and the test boat proceeded under its own power.

16.8.3 Results

The maximum speed achieved from a standing start in these tests was about 13 mph. Cavitation appeared to be one of the most critical factors, perhaps the limiting one, and, particularly in the earlier trials, vibration was intense.

When the boat was towed to a speed above the stern eddy range and then released, it could maintain a speed of 20 to 21.7 mph.

Tests of the three basic forms of disk investigated (flat, warped, and removed segment of ellipsoid) indicated that the warped and the ellipsoid shapes give the best results, with the warped type giving slightly smoother operation.

While it was found possible to batter and dent the disks on hard ground, it was virtually impossible to destroy their propulsive power. In all of the marine growths in which the boat was tried, the sine disk propeller appeared to be entirely immune to fouling.

The boat steered satisfactorily at all but the very lowest speeds.

16.8.4 Conclusions

The maximum speed achieved (about 44 per cent of that expected) appeared to be limited by cavitation, unsuitable engine to propeller ratios, uncontrolled depth of immersion, and a hull design unsatisfactory for this type of propeller.

Further development may well be undertaken on application of the sine disk propeller to the planing type of hull to be used in comparatively high-speed aircraft rescue boats, and to the nonplaning type, where the advantages of shallow draft, nonfouling, and structural durability can be useful.

Independent observations led to the conclusion that in the tests undertaken either the disks were too small to propel the boat properly or the gear ratio was too high for the engine to turn disks large

[a] C. H. Van Patten, Detroit, Michigan.

[aa] This investigation was conducted by the E. F. Jacobs Company, Detroit, Michigan, under OSRD contract OEMsr-1186 and Sparkman & Stephens, Inc., New York, New York, under OSRD contract OEMsr-???.

enough to give the necessary propulsive thrust. No simple, practical method was achieved to permit critical analysis of the performance of the sine-disk propeller.[55]

18.9 COLD-WEATHER STARTING[56]

In the summer of 1942, the Ordnance Department requested an investigation which would facilitate starting tank engines after they had been exposed to temperatures as low as −40 F. Assistance was requested specifically on the development of (1) a shutter arrangement operated from inside the tank for heating the engine and the oil lines during starting periods, (2) a primer pump for oil dilution, (3) space heaters for maintaining minimum temperatures of 5 to 10 F during nonoperating periods and for heating the battery, oil line, and engine during starting operations, (4) an immersion heater to be operated from the storage battery to heat the oil in the reservoir, and (5) a conversion kit for installation of the above equipment on tanks in service.

While this investigation was under way, the Army itself developed shutters which appeared satisfactory, and several primer pumps and space heater designs were made available for consideration.

Major emphasis was placed on the immersion heater with a design finally being developed for a coil to heat the oil at the sides and bottom of the reservoir and around the reservoir outlet at the base of the hopper.[57] In laboratory tests with oil having a pour point of 0 F, this unit required 10 minutes to warm the oil from −16 F to a fluid state.

With these developments and the equipment installed on tanks for the winter months, the Ordnance Department advised that the work under the original directive had been successfully completed, and the project was terminated.

56 Project OD-62.

57 Galrod Heater manufactured by General Electric Co., Schenectady, N.Y.

Chapter 19

SPECIAL STUDIES

19.1 SHIP TURNING RESEARCH

Summary

In order to investigate the principal hull factors affecting the turning of ships, particularly destroyers, a turning basin was constructed and measurements conducted on a series of models representing several variations of round- and V-bottom destroyer hulls and on a series of hulls covering the transition from destroyer to PT boat proportions. Additional studies were made on actual Navy ships.

In general, it was found that short turning is favored by a deep profile forward and a shallow profile aft, smooth afterbody sections, increased displacement, twin rudders, and the presence of bilge keels.

At the termination of the project under NDRC direction, work was continued under Navy supervision.

19.1.1 The Problem

At the request of the Navy, work was undertaken early in 1942 to determine the principal hull factors affecting the turning of ships. The eventual goal was the improvement of such ships as destroyers, which were believed to suffer particularly from deficient turning characteristics. It was determined that the investigation should begin with tests of systematic hull variations in order to establish trends and provide general background and should later include a study of steering.

In maneuvering against an enemy, a warship must frequently turn sharply through 90 or even 180 degrees. It is of the highest importance that this maneuver be carried out (1) with a minimum turning circle, (2) with minimum loss in speed, and (3) without undue heel. The behavior of a ship in making such turns appears to depend upon (1) the form of the underwater body, (2) the rudder area, (3) the rudder angle, (4) the position of the rudder or rudders in relation to that of the propeller or propellers, and (5) the speed of the ship.

Before 1939, this type of investigation consisted largely, in this country, of model turning tests conducted in the Experimental Model Basin at the Washington Navy Yard. These were limited to partial turns. In 1939, turning tests were made in the Stevens Institute swimming pool in order to observe the heel of a destroyer model during turning. In 1941, turning tests of three competitive motorboat designs were made in the somewhat larger swimming pool at Columbia University. In 1941 and 1942, a comparative study was made by the Navy of the turning of two destroyer models and three cruiser models in an effort to discover why destroyer turning circles are relatively larger than cruiser turning circles. These early tests showed that (1) turning tests of small models are generally satisfactory and (2) a tank somewhat larger and more conveniently arranged than a swimming pool is necessary to handle any considerable volume of work.

19.1.2 Procedure

In order to conduct an investigation requested by the Bureau of Ships,[a] it was necessary to construct a suitable turning basin and to equip it with the facilities necessary for investigating the turning characteristics of high-speed ships. This was desired in order to permit analysis of cruiser turning; equal attention was, however, focused on destroyers, which then were performing antisubmarine duty and which required improved maneuvering. The maneuvering tank built for this purpose is 75 feet square and 4½ feet deep, with a 25-foot extension at one corner to provide additional length for straight approach runs.

In this tank, the comparative turning tests were conducted on 18 hull variations of a round-bottom destroyer, on 13 hull variations of a V-bottom destroyer selected because of its good turning, and on a group of V-bottom hulls which covered the transition from destroyer to PT boat proportions. Other tests were conducted on the effect on turning of various appendages, such as bilge keels, and of changes in the number, size, and relative angular displacement of rudders, in propeller size, and in relative propeller speeds. Statistical and analytical studies were carried out on tactical data derived from trials made for the Navy on 22 models and 18 ships. The lateral rudder

[a] This investigation was conducted by the Stevens Institute of Technology, Hoboken, N. J., under OSRD contract OEMsr-154.

force of a few representative models, both in turning and in straight line motion, with yaw, was measured and analyzed.

In general, the tests were divided into two basic types:

1. The measurement of the approach and turning path at various conditions of speed and rudder angle.
2. The measurement of the lateral rudder force in free turning at various rudder angles and of the lateral hull force and hull moment in straight-line motion at various yaw angles.

The first group concerns the geometry of turning, the second, the forces operative in steering and turning.

In addition to the turning tests, resistance tests were also run on many of the models investigated, particularly on the variations of a round bottom destroyer, in order to show the influence upon resistance of the hull variation under investigation.

Various other projects, nearly all of them bearing directly on the turning problem, included comparative model tests made in cooperation with the Taylor Model Basin, shallow water tests to investigate the possible effect of shoal water upon the results of tactical trials, resistance tests of heavy displacement models, conducted at the request of the War Department, and the design and construction of a three-component rudder dynamometer for use at the Taylor Model Basin in measuring the lift, drag, and torque on the rudder of large models.

Some of the foregoing work was interrupted at the request of the Navy for high priority measurements and study of tactical data for models of some 22 naval vessels, to be used by the forces afloat, and for the execution and analysis of full scale tactical trials of 13 naval vessels. All of this work was covered by separate contracts with the Navy.

10.1.3 Results

From the information obtained before this contract was terminated and the project transferred to the Navy, it is possible to draw certain over-all conclusions on the relationship of hull proportions and turning.

1. *Profile.* A deep profile forward and a shallow profile aft combine to favor short turning. The stern of a ship has a pronounced lateral motion during turning, and a high profile aft minimizes the resistance to this motion. This is substantiated by tests at abnormal trims: static trim by the bow improves turning, while static trim by the stern impairs it.

2. *The afterbody shape.* Smooth afterbody sections—that is, the absence of sharp chines or angular sections—and the reduction of dead wood or removal of a skeg improve turning.

3. An increase in *displacement*, *displacement-length ratio*, or *beam-draft ratio* slightly improves turning.

4. Although the *propellers* of a turning ship do not both rotate at the same rate, even with the throttle remaining undisturbed, it is satisfactory to conduct model tests with all propellers rotating at the same speed.

5. Smaller turning circles with the same *average rudder angle* can be obtained with ships having twin rudders if the rudder nearer the center of the turn is turned more than the average and the other rudder is turned less than the average.

6. *Twin rudders* are much more effective than a single rudder.

7. The presence of *bilge keels* results in a reduction in the size of the turning circle but in an increase in outward heel during turning.

A correlation of a large amount of tactical data has shown that, when turning in circles of similar size (measured in terms of ship length), all ships have much the same relative turning geometry, i.e., advance, transfer, and speed reduction. This indication has simplified the approach to further studies.

10.1.4 Recommendations

The ultimate aim in these investigations was the development of operational data covering a sufficiently wide variety of forms of underwater body, rudder area and angle, and similar factors that the results could be expressed as functions of two or three parameters involving all of the factors influencing the performance of a ship in turning. These parameters should be expressed in such a manner that, given a proposed ship operating under proposed conditions, the diameter of the turning circle and the loss of speed can be read from a suitable form of chart.

This end lies yet in the future, but the information acquired marks considerable progress toward the goal.

At the termination of this project under NDRC, work was already under way toward four major objectives. First, measurement of forces and turning

characteristics should be continued on four more of the group of models representing a typical spread of hulls. The data obtained in this study should be correlated with the equations of motion to ascertain the influence of the several hull variables represented. On the basis of the information obtained from the two foregoing studies, tests should be conducted on a short, consistent, exploratory series of hulls and carried out to show the type of range of hull variables which must be investigated to provide general design information. Then, as a logical step, tests should be conducted on a more complete series of hulls to provide fundamental data for use in design. It appeared that future investigations should be directed toward obtaining suitable empirical data so that a basic theory (equations of motion) can be transformed into workable design information on turning and steering. Achievement of this goal would mark a considerable improvement over the available "cut and try" method based on rule of thumb data.

19.2 CAVITATION RESEARCH[b]

At the request of the Taylor Model Basin of the U. S. Navy Bureau of Ships, work was begun in the summer of 1943 on a study of the cavitation produced by various shapes of noses and tail pieces.[c] Before this project was terminated, a water tunnel was constructed, together with several interchangeable noses and a supporting cylindrical shaft. Each nose contained necessary leads for piezometric measurements. Provisions were also being made for high speed photographic recording of the onset, physical forms, and characteristics of cavitation as the speed is gradually increased from low to cavitating velocity.[d]

19.3 THE PHYSICAL CHARACTERISTICS OF SNOW AND THE PERFORMANCE OF SNOW VEHICLES

Summary

In an attempt to correlate the performance of different vehicles, including the Weasel, on snow characterized by different properties, it was found that vehicle performance is affected by the density and depth of the snow, the penetration into the snow at different ground pressures, the water content of the snow, and, particularly, the shearing strength of the snow at different ground pressures. In general, the shearing strength is the principal controlling factor and is apparently the limiting factor on maximum climb. The water content of the snow parallels the icing condition on moving metal parts, and a high water content in certain types of snow drastically lowers the shearing strength. Depth and penetration affect operation on the level and on hills. The density of the snow does not appear to have a direct bearing on vehicle performance but is involved in determining the proportions of air, water, and ice. The depth as such does not seem to affect the rolling resistance of the vehicle but is important in its effect on the penetration necessary to compress the snow sufficiently to support the vehicle.

Correlation of these factors with meteorological conditions has shown that it is possible to make satisfactory forecasts of vehicle performance not merely for a period of 12 to 24 hours but, under certain circumstances, for several days ahead.

19.3.1 The Problem

As part of the development of the Weasel,[d] it appeared highly desirable to conduct a parallel investigation on the terrain over which this snow vehicle was expected to operate. It was apparent at the outset that not only were the major physical characteristics of snow in their relationship to vehicle performance poorly understood, but even the identity of some of these characteristics was unknown. It was likewise evident that the properties of snow may vary over an extremely wide range and may change from one extreme to another in a very short time.

Since the Weasel was being prepared as both a logistical and a tactical vehicle for use in what was to be a carefully planned winter invasion, it was essential that an additional investigation be conducted on both short and long range forecasting of snow conditions. Successful methods derived from this phase of the study would make it possible to indicate the probable speed, hill climbing ability, and maneuverability of the Weasel over a known terrain well in advance of the actual operation.

b Project NS-203.

c This investigation was conducted by the Hydraulic Research Institute of the State University of Iowa, Iowa City, Iowa, under OSRD contract OEMsr-1127, first under the supervision of Section 12.3, later under Division 6, and finally under the Navy.

d See Chapter 5 in this volume.

Procedure

Active work on this problem began in August 1942 at the Columbia Ice Fields, Saskatchewan, Canada, during the tests of the first Weasel pilot models on the Saskatchewan Glacier. Additional work was carried out in the Columbia Ice Fields in October 1942, while other studies were made at Camp Hale, Colorado, from February to May 1943 and at Pinkham Notch, New Hampshire, in February 1943.

Nomenclature

Snow as it appears on the ground may be classified as freshly fallen snow, settled snow, crusted snow, and firn snow, and each of these broad groups may be subdivided into several subgroups determined by conditions of radiation, wind, and temperature during their life history. From the point of view of vehicle performance, these various types of snow may be classified as follows.[*]

A. *Freshly Fallen Snow*

1. ***Wet flakey snow*** – temperature 32 to 30 F; wet, highly compressible, and coherent; density varying from 0.1 to 0.4; water content up to 25 per cent.

2. *Dry flakey snow* – temperature 24 to 32 F; compressible and coherent; density about 0.2.

3. *Powder snow, dry* – temperature varying greatly from about 30 F to about 10 F; compressible but poorly coherent; density below 0.2.

4. *Tough powder or flour snow* – temperature +10 to −20 F; compressible but incoherent; density in the vicinity of 0.2.

5. *Wild snow* – temperature below about 20 F; very fluffy, like "diamond dust"; density below 0.05.

B. *Settled Snow*

6. ***Sun toughened snow*** – usually 2 or more days old; density 0.2 to 0.3; compressible and coherent.

7. *Wind toughened snow* – no appreciable crust but firm; density 0.2 to 0.3; compressible but poorly coherent.

8. *Snow cushion* – snow that has been deposited by wind, occurring at low temperatures and resembling tough powder snow (see above) except that its density is greater.

9. *Wind slab* – resembles snow cushion but is harder and more unstable, since it does not adhere to the snow surface beneath. (Note: Wind slabs and snow cushions, like cornices, are local phenomena and are of interest only as formations that should be avoided.)

10. *Sand snow* – occurs at extremely low temperatures; incoherent and incompressible, rough like sand, with no glide; density about 0.4 to 0.5.

C. *Crusted Snow*

Light crusts may be present on top of loose snow, but strong crusts are usually supported by dense snow. Carrying strength depends mainly on thickness, but the relationship was not determined.

11. *Wind crust* – formed through the drifting of coherent snow; usually rough surface with skavler and erosion marks; density 0.3 to 0.5.

12. *Sun crust* – formed through repeated melting and freezing of the snow surface exposed to sunshine; usually smooth; density 0.3 to 0.5.

13. ***Rain crust*** – formed through freezing of the snow cover after rain; usually hard like ice.

D. *Firn Snow*

Through repeated melting and freezing, the snow develops a granular structure, with a frozen crust during cold spells (nights) and a soggy, granular composition in warm periods (days). Three types are noted.

14. *Spring snow* – slightly granular; density 0.3 to 0.4; wet, with water content about 5 per cent in the middle of the day; compressible and coherent.

15. *Corn snow or moderate firn snow* – large whitish grains with a tendency to ice; water content 5 to 15 per cent in the middle of the day; density about 0.5; poorly coherent, not very compressible.

16. *Coarse firn snow* – large opaque grains, sometimes ice; very wet and soggy; water content about 20 per cent during warm spells; density 0.5 to 0.6; compression and cohesion extremely limited.

Surface frost and thin rime crusts may form on the surface of any of the above types but do not affect vehicle performance.

The nomenclature in the foregoing outline will be used in the rest of this report.

Observations

In planning the actual measurements to be made, particularly those to be taken on the Saskatchewan Glacier, it was felt that two main principles should

[*] This investigation was conducted by personnel of the Brooklyn Polytechnic Institute, Brooklyn, New York, under OSRD contract OEMsr-858 and a representative of the Norwegian Army in cooperation with personnel supplied by the Studebaker Corporation, South Bend, Indiana.

be used as guides: (1) the tests should be so quick and simple that they could be carried out on the proving ground right next to the operating vehicle, and (2) the experimental setups should not differ significantly from those used in earlier snow research, so that the results could be compared.[27]

Density. The weight of a known volume (about 2 liters) of snow was determined with a spring balance. When made at virtually the same time at the same location, the measurements varied about 1 to 2 per cent. Under the conditions on the Saskatchewan Glacier, the observed densities were between 0.53 and 0.60, marking a typical heavy snow. In spite of the fact that the density remained practically constant and therefore was an inappropriate factor for consideration as a parameter, density measurements were made throughout the entire period of observation. In other areas, particularly at Camp Hale, values as low as 0.07 were found.

Temperature. The temperature of the snow was measured 1 to 2 inches below the surface and remained very close to 32.00 ± 0.05 F in that region. At depths of 2 to 5 feet, however, the snow temperature dropped gradually from 31 to 30 F. Air temperature measured from 6 to 8 inches above the snow surface varied according to weather conditions from 21 F on a cool morning to 47 F on a warm afternoon. Air temperature showed a marked relationship to the mechanical and physical properties of the snow, with rising temperatures always accompanied by higher water content, increased penetration, and decreased shearing strength. Quick and temporary variations in air temperature, caused by sudden breezes or drifting clouds, had no measurable influence on snow properties.

Water Content. The heat of melting of a known weight of snow was determined calorimetrically and gave the water content, which, varying from 2.5 to more than 25 per cent during a warm day, was found to be intimately connected with shearing strength and penetration. The greater the water content, the softer and weaker was the snow. Microscopic observation indicated that this is due to the fact that each spongy snow grain becomes enveloped in a thin film of water which not only interrupts the interlocking of the particles but actually has a definite lubricating effect. In such a condition the grains "swim" in water. A similarly striking correlation was found between high water content and icing of the metal parts of the vehicles. Icing became apparent when the water content reached 15 per cent and was always very severe at 25 per cent.

Shearing Strength. Shearing strength tests were conducted by shearing off a snow column supported by two metal tubes. The results are expressed in psi. The accuracy of this test should not be overestimated, since the strength of the snow columns in the tubes depends considerably upon the method used to bring the snow into the tubes. If the same procedure is followed in every case, the measurements can be reproduced within ± 30 per cent.

Shearing strength usually showed a very marked change during the day. After a cool night it was often too high to be measured. At about 1000 hours, after the sun had worked on the snow for 2 or 3 hours, values of 1.5 to 1.8 psi were obtained. Toward 1200 hours the shearing strength dropped very quickly and in the early afternoon at about 1400 hours reached values of 0.30 psi and less. If clouds appeared during the day, the drop in shearing strength stopped abruptly and values of about 0.6 psi were observed all during the afternoon. At about 1630 or 1700 hours, as the air temperature started to go down, the shearing strength increased.

If the night were warm (about 36 F) with shearing strength values of about 0.6 or 0.8 psi, these values dropped during the day as soon as the sun touched the snow surface. On a cloudy day with little or no direct sunlight, however, the shearing strength remained constant throughout the day.

Penetration. In this test, which was carried out mainly because earlier workers had reported a series of such measurements, the depth and penetration were measured for a weight falling from a height of 10 inches above the snow. The values cannot be converted directly into any rational quantity, such as compressibility, shearing strength, or the like. The penetration can be measured in a few seconds and the individual tests checked to about 25 or 35 per cent of their own value. In the morning after a cool night, penetration was usually found to be about 0.25 inch or less, characteristic of the hard, old snow on the Saskatchewan Glacier. Later during the day, penetration increased to about 2.5 inches and also varied inversely as the shearing strength. Since this test can be made without removing a sample, it offered an opportunity to study the local conditions of a snow surface of specific interest in connection with a vehicle test; thus, it was possible to measure the penetration value in the track of the Weasel after

the vehicle had passed and to see which parts of the track were compressed and reinforced and which were loosened and weakened. It was also possible to compare the penetration into the snow on the sunside and on the shadow side of the small snow hills which covered nearly all the glacier proving ground. These measurements revealed the occurrence of great local variations, with a penetration value of 2.0 inches observed on the sunside and a value of only 0.30 inch at a point perhaps 5 or 6 inches away on the shadow side. It was evident, therefore, that small crusts or disks of relatively hard snow are frequently distributed in a soft matrix, but as long as these hard portions are not coherent, they contribute little to the apparent average shearing strength of the snow.

Other Tests. It may be pointed out that there is no reason to believe that the tests described above provide the best or simplest means of characterizing a given snow condition. Most probably they provide only a very crude solution of the problem of numerically representing snow properties. Selected from the point of view of expedience and simplicity, they showed some definite weaknesses and disadvantages.

Several additional tests were contemplated but either applied only irregularly or not used at all. For example, it was planned to measure the shearing strength of a snow sample after a previous compression—a test which would lead to a curve of shearing strength versus ground pressure. The snow on the glacier, however, did not lend itself readily to this test, and accordingly such curves were extracted from other information.

Methods of Prediction

In order to develop methods of predicting the characteristics of snow and thus to forecast the performance of a snow vehicle, the procedure adopted was the obvious one of studying the life history of snow under various conditions and then determining which meteorological factors seemed to be related to the physical characteristics of the terrain.

19.8.3 Results

Physical Characteristics of Snow

The measurements made as described above yielded an abundance of information on the different factors selected for study and on the relationships between them. Figure 1 gives the penetration-ground pressure curves for four types of snow as studied on the Saskatchewan Glacier in August and October

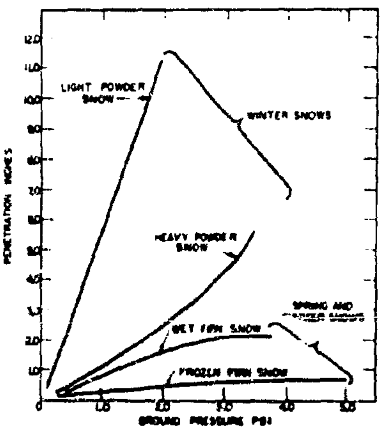

Figure 1. Relationship between snow penetration and ground pressure. Saskatchewan Glacier. August and October 1942.

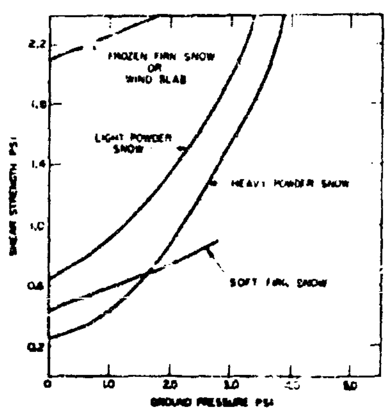

Figure 2. Relationship between snow shearing strength and ground pressure. Saskatchewan Glacier. August and October 1942.

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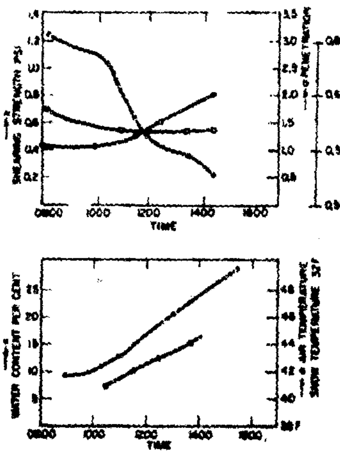

FIGURE 3. Changes in shearing strength, penetration, density, water content, and air temperature (snow temperature = 32 F) from about 0800 to 1600 hours on bright sunshiny day with no winds or clouds, August 5, 1942, on Saskatchewan Glacier.

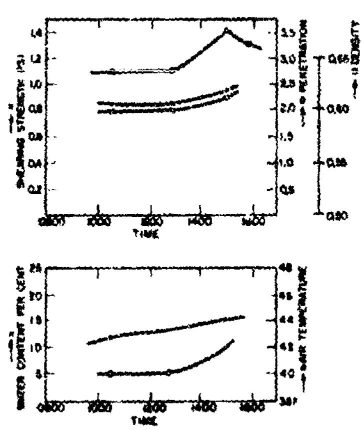

FIGURE 4. Changes in shearing strength, penetration, density, water content, and air temperature (snow temperature 32 F) from about 1000 to 1600 hours on cloudy, moderately windy day after rain preceding evening. Data obtained on August 7, 1942, on Saskatchewan Glacier.

1942. Curve 1 illustrates the penetration in frozen firn snow (density about ..) found on cold nights in August; this type provides the best support for a vehicle. Curve 2 represents the penetration in wet firn snow (density about 0.5) encountered on a warm afternoon in August. Over all such terrain, pilot model Weasels sank to a depth of about 2 or 3 inches. Curve 3 shows the penetration in heavy powder snow (density about 0.25) observed in October, with a vehicle penetration of about 4 to 6 inches. Curve 4 gives the penetration in light powder snow (density about 0.17) found in drifts, here the vehicle sank to about 12 to 14 inches.

Figure 2 gives the shearing strength-ground pressure curves for the same four types of snow. It can be seen that frozen firn has a very high shearing strength and, therefore, may be expected to enable a vehicle to climb such terrain at a high angle. Curve 2 shows that wet firn snow is definitely less resistant, although it gains some strength upon compression. Curves 3 and 4 show the characteristic behavior of light and heavy powder snow encountered on the glacier in October.

The water content of the various types of snow was characteristically different, ranging from about 0 per cent for frozen firn snow, light powder snow, and heavy powder snow to about 20 per cent for wet fresh snow and 27 per cent for wet firn snow.

The variations in the characteristics of snow under changing atmospheric conditions are illustrated by Figure 3, which shows the changes in shearing strength, penetration, density, water content, snow temperature, and air temperature over about an 8-hour period. This figure is based on the results of measurements made on August 5, 1942, on the Saskatchewan Glacier on a bright sunshiny day with no wind or clouds. Figure 4 presents similar information for August 7, 1942, with a cloudy sky, moderate winds, and the snow uniformly wet after rain the previous evening.

Correlation with Vehicle Performance

A study of the varying characteristics of snow and of the performance of vehicles operating on snow has indicated that useful correlations can be made. This concerns such aspects of performance as climb

ing ability, penetration, speed, and power consumption.

Climbing Ability. If a vehicle weighing Q pounds and having two equal tracks each l inches long and m inches wide is placed on a slope at an angle θ to the horizontal, then the normal pressure or ground pressure p in pounds per square inch, is given by

$$p = \frac{Q}{2ml}\cos\theta = 2\cos\theta, \tag{1}$$

while the tangential shearing stress in pounds per square inch is given by

$$s = \frac{Q}{2ml}\sin\theta = 2\sin\theta. \tag{2}$$

If the vehicle adheres completely and if there is no surface gliding between track and snow, the limiting angle of climb is given by the shearing strength S of the snow on which the vehicle operates. As long as the stress s of equation (2) is smaller than the shearing strength S, the snow will support the Weasel; as soon as s becomes larger than S, the snow underneath the vehicle will be sheared off and the vehicle will start to slide down the slope.

In the case of the Weasel, with Q about 4,000 pounds, l 60 to 80 inches, and m 15 to 18 inches,

$$\sin\theta = \frac{S}{2}, \tag{3}$$

where S is the shearing strength of the snow underneath the tracks. If the shearing strength of the snow does not depend very much upon ground pressure and if the ground pressure is small (around 1.5 or 2.0 psi), then it is permissible to identify S with the value as measured in the shearing strength apparatus. Hence, we may apply equation (3) to determine which slopes can be climbed.

By taking one of the lower shearing strength values observed during the test runs, e.g., 0.40 psi, it is evident that $\sin\theta = 0.20$, which corresponds to an angle of climb of about 12 degrees. Such slopes were found to be those on which the Weasel began to fail if the snow was soft and weak.

Equations (1) to (3), however, describe highly oversimplified cases. The most important factor is the dependence of the shearing strength on ground pressure. This can be included by putting

$$S = a + bp^c, \tag{4}$$

where a represents the shearing strength without any ground pressure and may therefore be called the cohesion of the snow; and where b and c are two empirical constants which together characterize the behavior of the individual snow sample under consideration. In the case of fluffy, wild snow, a is about 0.20, and in the case of very soft, heavy snow, it increases to only about 0.30. For hard, heavy snow, however, it assumes values between 0.80 and 2.00. Probably a is rarely less than 1.00 or greater than 2.00. In heavy snow, either soft or hard, a is about 1.00 and in such cases b is small—0.05 or 0.10—and consequently the ground pressure does not appreciably affect the shearing strength. For fluffy, wild snow with a about 0.20, b is about 0.50, which indicates that ground pressure increases the shearing strength and that the second term in equation (4) is most important.

In order to get a more general estimate of the limiting angle of climb, the equivalent of p in equation (1) may be introduced into equation (4), giving for the shearing strength of the snow underneath the vehicle

$$S = a + b\left(\frac{Q}{2ml}\cos\theta\right)^c. \tag{5}$$

If a is about 1.00 and the value of b is small, the terrain is heavy snow, soft or hard, as treated in equation (3). For wild snow, it appears that the vehicle will just fail to climb when the shearing stress s which it produces [equation (2)] equals the shearing strength S [equation (5)], as indicated in equation (6):

$$\frac{Q}{2ml}\sin\theta = a + b\left(\frac{Q}{2ml}\cos\theta\right)^2. \tag{6}$$

If the snow is very fluffy and the ground pressure no greater than 1.5 to 2.0 psi, the value of a (0.20) at the side of the second term can be neglected. Thus,

$$\frac{\tan\theta}{\cos\theta} = bp. \tag{7}$$

Comparison of equations (2) and (7) shows that on heavy snow the climbing potential decreases as ground pressure increases—an obvious relationship, since it is assumed that the shearing strength of the snow is independent of ground pressure, while the

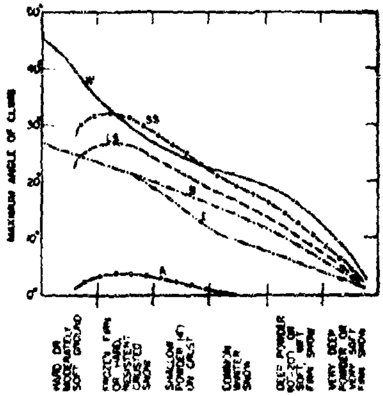

Figure 5. Hill climbing ability of snow vehicles in various types of snow. (A) Aero-sled, (B) Bombardier, (E) Eliason toboggan, (LS) large Archimedean screw vehicle, (SS) small Archimedean screw vehicle, (W) Weasel

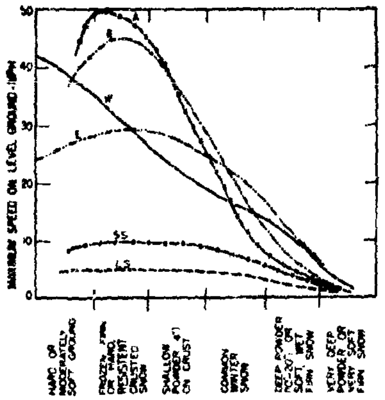

Figure 6. Maximum speed on level of snow vehicles in various types of snow. (A) Aero-sled, (B) Bombardier, (E) Eliason toboggan, (LS) large Archimedean screw vehicle, (SS) small Archimedean screw vehicle, (W) Weasel

shearing stress decreases with decreasing ground pressure. On fluffy snow, however, the limiting angle of climb increases with ground pressure, because the precompression solidifies the structure of this type of snow and increases its shearing strength.

Calculation of theoretical maximum climb based on the foregoing equations gave results which did not deviate significantly from the actual performance of the Weasel on the Saskatchewan Glacier. It seems possible, therefore, to prepare curves of climb performance in which the maximum angle of climb for a vehicle is plotted against the type of snow on which it operates. Such curves are given in Figure 5 for the Weasel and for five other vehicles tested at the same time under the same conditions. The classification of the various snow types is oversimplified but includes those which are likely to be encountered most frequently.

Penetration. In various types of snow, the Weasel was found to penetrate from 0 inches on supporting crust to 20 inches or more. The depth of penetration as such does not appear to affect the rolling ability of the vehicle, but the penetration necessary to compress the snow to support the unit vehicle weight contributes significantly to rolling resistance on the flat and increases the net angle of climb by the angle of the rut to the slope. This rut angle has varied from 4 degrees at 10-inch penetration on a 19 degree slope to 12 degrees at 5-inch penetration on a 24 degree slope. Computed variations in ground pressure were not found to agree with the penetration actually observed with various types of vehicles in motion.

Speed. Maximum speed on level ground was found to be closely connected with the depth of track penetration and with the compression of the snow. Although these factors were not considered suitable for a thorough theoretical treatment in this investigation, it was possible to prepare speed performance curves on the basis of actual measurements on different types of snow. These speed curves, similar to the hill climbing curves in Figure 5, are presented in Figure 6.

Power Consumption. An analysis of the power requirements for such a vehicle as the Weasel moving on snow has shown that penetration and speed are the two most important factors influencing power consumption.

Prediction of Vehicle Performance

In order to make maximum use of the correlations established between the physical characteristics of snow and vehicle performance, it was necessary to develop methods for both long- and short-range prediction of vehicle performance. This involved first a

study of the characteristic setting mechanisms undergone by freshly fallen snow exposed to various weather conditions, and second a study of "typical daily fluctuations" which a given type of snow may undergo during a day of given weather conditions.

A review of the measurements obtained, particularly of those made at Camp Hale, indicated that certain typical mechanisms could be established for the *setting* of snow. These mechanisms depend upon the prevailing weather conditions and are related to certain characteristic *types of setting*. From the observations obtained, the following mechanisms seem important:

1. Cold weather setting through evaporation.
2. Cold weather setting through wind action.
3. Warm weather setting through superficial melting.

As long as any of these mechanisms prevails over a given period, it appears that the general properties of a snow may be predicted with a fair degree of accuracy over a period of several days.

Even with some overlapping between two of these mechanisms, it may still be possible to make reasonable predictions as long as the weather conditions during the critical period are known. If a snow layer has been sufficiently characterized by appropriate measurements, it appears possible to predict its daily fluctuations with fair accuracy if the meteorological conditions during the day can be forecast accurately. The properties of the snow can then be predicted with the aid of empirical fluctuation curves for typical days, such as "calm, cold day," "windy, cold day," "warm, cloudy day," or "warm, sunny day."

Long Range Predictions

From the point of view of shearing strength and compressibility, it is important to know whether settling at subfreezing temperatures occurs in any given case preponderantly by evaporation or by drifting. If evaporation plays a major role, a snow layer gains little in mechanical strength while it consolidates, because sublimation produces holes and cavities between snow particles and the material is not appreciably reinforced. On the other hand, if drifting is considerable during settling in subfreezing weather, it may be expected that a wind crust will appear, increasing the shearing strength and decreasing the compressibility of the layer.

Measurements at Camp Hale indicated that if cold, dry weather with moderate wind is expected, it is reasonable to predict that (1) density will increase very slowly, (2) evaporation will keep the snow fluffy, (3) no crust formation will occur, and (4) the shearing strength will remain very low (less than 0.8 psi at 2.0 psi ground pressure). Such conditions are highly adverse for the operation of a snow vehicle. If this type of settling occurs frequently or continuously, unfavorable conditions may last for many weeks.

On the other hand, if meteorological conditions indicate a period of cold, moist weather with moderate or considerable wind, Camp Hale studies showed that (1) the density of the snow will increase relatively quickly, (2) there will be little or no evaporation, (3) the snow will set faster, (4) crusts will form, and (5) shearing strength will increase (generally up to about 1.5 psi at 2.0 psi ground pressure). Snow setting under these conditions provides relatively favorable terrain for vehicle operation and after one week or so leads to what has often been termed "ordinary winter snow." This is a snow layer 2 to 3 feet deep with an average density between 0.20 and 0.30, a comparatively strong crust, and a shearing strength between 1.5 and 2.5 psi at 2.0 psi ground pressure.

The third type of setting—that which occurs in warm weather—seems to involve melting as a main process, with the uppermost layer melting during the hours when the temperature is above zero and with the liquid draining down and refreezing as soon as it reaches the colder layers underneath. After a certain amount of snow is removed in this way from the top layer, the rest of the layer collapses and forms a new and somewhat denser structure. This structure freezes during the hours of subzero temperatures to give the familiar snow crust or melt crust which marks this type of setting. Snow exposed to these conditions is generally characterized by an increase in shearing strength and by a decrease in penetration.

Figure 7 illustrates the changes in density of snow exposed to different loads over a 10-day period. As it was expected, increased loads give a radically greater density.

Short-Range Predictions

A survey of the Camp Hale results on daily fluctuation in snow properties indicates that on typical "cold winter days" the shearing strength is lowest in the morning, rises slightly during the day, reaches a maximum plateau at about 1800 hours, and drops

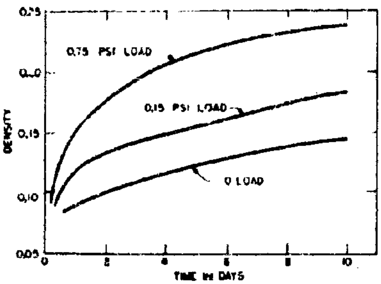

Figure 7. Increase in density of snow under different loads.

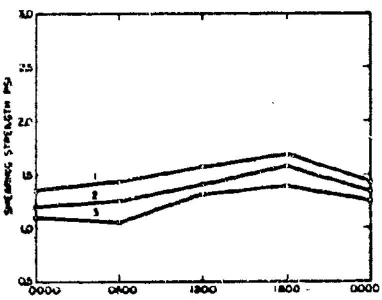

Figure 8. Typical "cold winter day" changes in shearing strength of snow over 24 hour period.

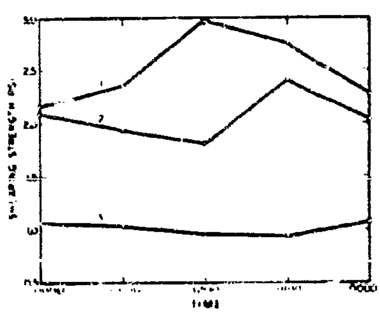

Figure 9. Typical "mild spring day" changes in shearing strength of snow over 24 hour period.

down again during the night (Figure 8). During "mild spring days," it is virtually impossible to make even approximate predictions, because these are too dependent upon uncontrollable local conditions (Figure 9). On "clear, cool spring days" and "clear, cool summer days," the shearing strength is very high in the early morning, decreases as the sun becomes more and more effective, reaches its minimum in the early afternoon, and then rises to reach its maximum value after midnight (Figure 10).

PREDICTION OF CLIMBING ABILITY

A further empirical method was developed for predicting the maximum climb of a vehicle from the depth of the last snowfall and the air temperature since the last snowfall. A diagram given in Figure 11 makes it possible to indicate that if, for example, 2½ feet of snow have fallen several days before and if, since then, the average temperature has been about 28 F, maximum climb of the vehicle will be between 17 and 18 degrees. Only a limited number of measurements were made during this study to support this method of prediction, but it seems to have a fairly sound general background.

18.4 WAKE VISIBILITY AND ITS SUPPRESSION

Summary

In an attempt to reduce the visibility of the wakes of small amphibious vessels used in landing operations, tests were conducted on chemical mixtures and mechanical baffles proposed as wake suppressors. Under the conditions of the tests, none of the mixtures or devices was found to possess any practical value.

18.4.1 The Problem

The wake of a moving vessel is generally its most conspicuous feature and may be detected under some conditions at distances at which the ship itself is practically invisible. In operations in the Southwest Pacific, for example, pilots reported detecting vessels by their wakes, particularly on moonlit or clear starlit nights, with or even without phosphorescence.

As part of a study[a] of the use of such vehicles as the DUKW in amphibious landing operations in combat areas, it was desirable to investigate the wakes of

[a] See Chapters 3 and 4 in this volume.

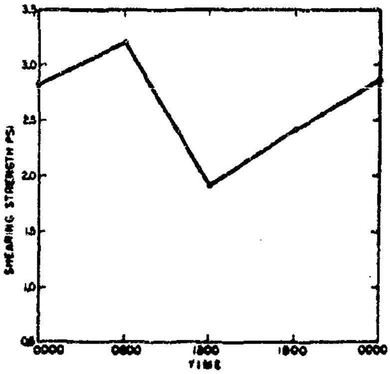

FIGURE 10. Typical "clear cool spring or summer day" changes in shearing strength of snow over 24-hour period.

small craft, the conditions under which these wakes might be most easily detected, and the use of various oils, dyes, spreading agents, smokes, and mechanical baffles proposed as wake-suppressors.[a]

[a] This investigation was conducted by the Woods Hole Oceanographic Institution, Woods Hole, Mass.

19.4.2 Procedure

With the exception of brief and preliminary experiments at Woods Hole, Massachusetts, the major part of the investigation was conducted in Florida waters near Fort Pierce, Cocoa Beach, and the Banana River in February and March 1945. One DUKW was used to carry the experimental equipment and operated with another DUKW acting as a control. Usually the two vehicles moved abreast on parallel courses about 900 feet apart. The DUKWs and their wakes were studied, and photographed where possible, by observers located at sea level, in shore towers, and in aircraft flying from nearly sea level to an altitude of 10,000 feet. Runs were made both in daytime and at night.

Foam Suppressor

Special foam suppressor equipment was installed on the experimental DUKW to spray streams of various mixtures from the bow and stern (Figure 12). These mixtures included: (1) Diesel oil and sea water, (2) Diesel oil, sea water, and a spreading agent,[b] and (3) solutions of dyestuffs.[c]

[b] Palmetic acid, oleic acid, stearic acid, diphenylamine and octyl alcohol were tested in turn, in concentration of 1 per cent by weight.

[c] Calco Chemical R 1616-22-1 and R 1616-22-2.

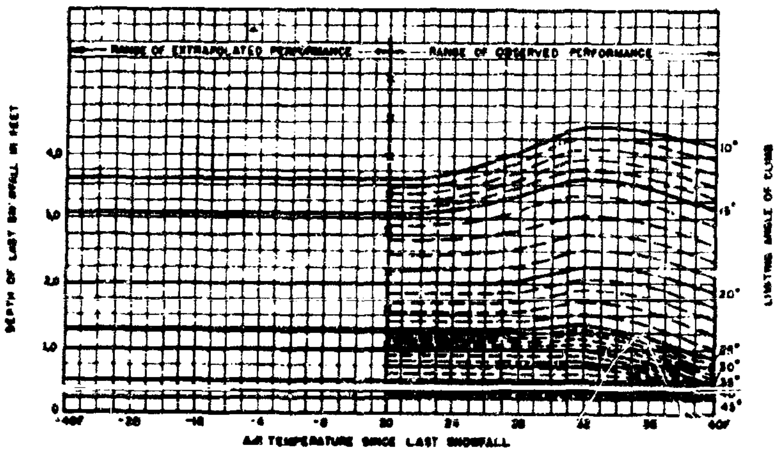

FIGURE 11. Curves for prediction of maximum Weasel hull climbing performance in snow.

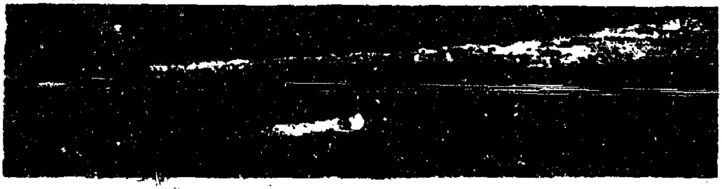

FIGURE 12. Use of foam suppressor equipment on experimental DUKW (lower). Woods Hole, Massachusetts.

BAFFLES

In order to reduce the visibility of the bow spray and of the stern geyser, a canvas bow curtain was hung from a hoop extending over the bow, and a tarpaulin was towed from the stern (Figure 13). Later, in order to prevent excess air from being drawn under the DUKW stern, a horizontal baffle was placed across the full width of the stern just below the water level.

18.4.3 Results

It was found that the foam suppressor, using Diesel oil alone or with mixtures of other agents, does reduce surface foam but does not appreciably reduce air spray or clouds of air bubbles, which appear downstream beneath the surface (Figure 12). The bow curtain and stern tarpaulin reduce air spray, but the surface foam remaining in the wake is not significantly affected (Figure 13).[33]

Tests performed in the Banana River clearly indicated the difficulty of suppressing wake visibility in turbid and foamy water (Figure 14).

The results of air observation are shown in Figure 15, which includes vertical and oblique views taken at altitudes up to 10,000 feet and at distances up to 4 miles. In each case, the experimental DUKW was equipped with a bow curtain, a stern tarpaulin, and a foam suppressor spraying a mixture of Diesel oil and salt water from bow and stern. In this series, the normal DUKW was painted khaki and the experimental DUKW, blue.

A general survey of the results showed that in *daytime* observations from the surface the hull is usually more obvious, especially if it is seen against the horizon, but that from the air the wake can be distinguished for many miles beyond the point at which the hull becomes invisible and is not only the most important but often the only feature revealing the presence of the vessel.

In *night* observations from sea level, the hull is more conspicuous with moonlight or bright starlight, while the wake is more distinguishable with strong phosphorescence. In night observations from the air, the relative importance of hull and wake varies greatly according to the circumstances. Thus, on moonlight nights, the hull can be distinguished for several miles and is more conspicuous than the wake; on dark nights, or with only moderate phosphorescence of the water, the wake is usually seen first; with strong phosphorescence, the wake may reveal the presence of a vessel from a distance of several miles; and on dark nights with no phosphorescence, neither hull nor wake can generally be seen.

FIGURE 13. Use of bow curtain and stern tarpaulin on experimental DUKW (lower). Woods Hole, Massachusetts.

19.4.4 Recommendations

The installation of foam suppressor equipment, particularly on the DUKW, was not recommended. The use of a bow curtain and stern tarpaulin might have some camouflage value against visual observation close to sea level. Further investigation might be profitably undertaken on the use of other baffles and on the use of black smoke to reduce the visibility of subsurface bubbles.

If further investigations should be undertaken in this field, they should be directed toward the suppression of wake visibility by daytime observations from the air and by night observations from either air or sea level during conditions of moderate or strong phosphorescence, in which the wake is usually more conspicuous than the hull and in which suppression would have most practical value.

FIGURE 14. Effect of foam suppressor equipment on experimental DUKW (lower). In foamy, turbid water, Banana River, Florida.

19.5 WIND AND WAVE STUDIES

Summary

Measurements of wind velocity, wave height, wave period, wave length, and the velocity of propagation of waves, followed by a correlation of these measurements, have made it possible to predict wave heights from wind velocities with reasonable accuracy in deep water as well as in coastal waters under certain conditions.

In currentless deep water, the wave height measured in feet is about 0.5 times the velocity in mph of a persistent wind. In coastal shoal water, the wave height in feet is about 0.3 times the wind velocity in mph.

19.5.1 The Problem

As part of the development and investigation of the DUKW and other amphibians intended for operation in surf and open sea, it was recommended by Division 12 late in 1942 that a brief study be undertaken on the relationships between wave characteristics and wind velocity.[1]

19.5.2 Procedure

From November 10 to December 7, 1942, observations and measurements were made off Provincetown, Massachusetts, on the characteristics of waves at different wind velocities.

Wind velocity was measured with two permanent, recording anemometers elevated high above water level and with two hand anemometers, all calibrated to give identical readings under identical conditions.

Wave height was measured from shore by transit observation of floating wooden blocks fastened on anchored barges 200 to 800 yards from the beach and equipped with long vertical bamboo rods marked with a foot scale. The height or amplitude of a wave was defined as the vertical distance between the lowest and highest points marked on the rods. Amplitudes up to 9 feet were measured in this manner, and even greater values up to 12 feet were estimated with a telescope by noting the up and down movements of vessels of known dimensions (lighters, freighters, DUKWs, etc.) standing farther out to sea.

Wave period was determined with similar equipment by noting the time for a floating mark to make 20 full oscillations. The longest period measured was 5.5 seconds.

Wave length was never measured accurately, but could be estimated on several occasions. In some cases the length of a wave could be judged by observing it as it travelled along the side of a ship with a known length, and in others by standing on a protruding point of land and looking through a transit or telescope perpendicularly to the direction of wave motion some hundred yards offshore. The greatest lengths observed in this study were between 80 and 90 feet.

[1] This investigation was conducted by personnel of Division 12 of NDRC and of the Brooklyn Polytechnic Institute, Brooklyn, N. Y.

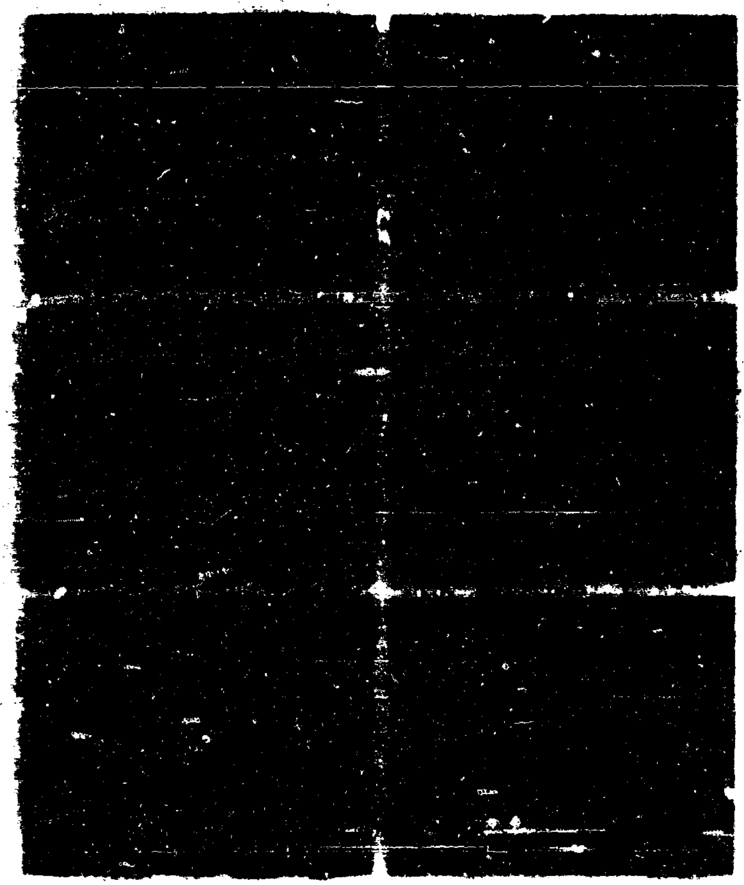

FIGURE 15. Air observation of wakes, Atlantic Ocean east of Banana River Naval Air Station, Florida. (Experimental DUKW equipped with foam suppressant equipment, bow curtain, and stern tarpaulin.

A. Observer 1,000 feet above DUKWs.
B. Observer 5,000 feet above DUKWs.
C. Observer 10,000 feet above DUKWs.
D. Observer 1 mile north of DUKWs at 1,000 feet.
E. Observer 2 miles north of DUKWs at 5,000 feet.
F. Observer 3 miles north of DUKWs at 10,000 feet.

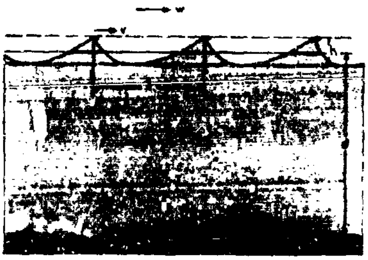

FIGURE 16. Factors involved in the correlation of wind velocity with characteristics of waves in deep water.

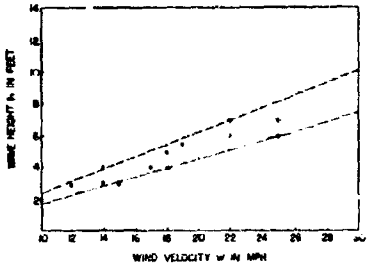

FIGURE 17. The effect of wind velocity on wave height in coastal waters.

Likewise, the *velocity of propagation of waves* could not be measured accurately but was estimated by observing with a transit or telescope the movement of the crest of a wave under an oblique angle. A certain distance of travel was then marked with a stop watch and the velocity estimated. Rates up to 20 mph were roughly determined in this way by means of this method of estimation.

19.5.3 Results

For a wave in deep water and under steady conditions (depth larger than wave length, far offshore),

$$v = \frac{g}{2\pi}t \qquad (8)$$

and

$$l = \frac{g}{2\pi}t^2 \qquad (9)$$

where v = wave velocity, l = wave length, t = period, and g = gravity. If v is expressed in mph, l in feet, and t in seconds,

$$v = 3.8\,t \qquad (10)$$

and

$$l = 4.8\,t^2 \qquad (11)$$

Figure 16 shows diagrammatically the conditions involved and defines the quantities under consideration. Equations (10) and (11) have been frequently checked by other workers and found to be reliable, provided that the depth of the water is much greater than the wave length, that the wind direction and velocity remain steady, and that no obstacles are encountered.[11] Periods up to 16 seconds have been observed in the open sea of the South Atlantic and South Pacific. These periods correspond to a propagation velocity of 57 mph and a wave length of 1,080 feet.

No fundamental theoretical relationships exist between wave velocity v and wind velocity w, nor between wave height h and wave period t. Very extensive observations, however, have established two

TABLE 1. Fundamental Relationships of Steady Waves in Deep Water

w in mph	v in mph		h in feet		l in feet		t in seconds	
	obs	calc	obs	calc	obs	calc	obs	calc
23	16	17.5	8	11.0	90	106	4.0	4.6
25	19	19.0	11	13.0	115	125	5.2	5.0
30	25	22.8	11	14.1	190	180	6.0	6.0
45	35	31.2	23	21.6	400	405	8.8	9.0
56	50	34.0	28	24.0	440	500	9.5	10.0
75	56	57.0	37	36.0	1,080	1,125	16	15.0

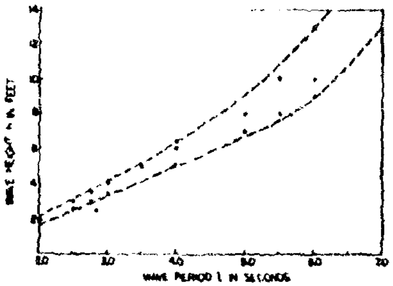

FIGURE 18. Wave height as a function of wave period.

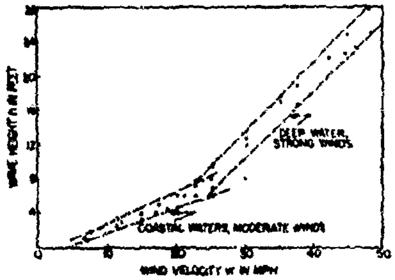

FIGURE 19. The effect of wind velocity on wave height in coastal waters and in deep water.

empirical relationships which seem to hold fairly satisfactorily if the conditions mentioned above are fulfilled. These are

$$v = 0.76\, w \tag{12}$$

and

$$h = 2.4\, t = 0.18\, w, \tag{13}$$

where w and v are measured in mph, h in feet, and t in seconds.

Waves in Deep Water

The measurements obtained by the methods described above are given in Table 1, together with the values derived from equations (10), (11), (12), and (13). It appears that these equations are reasonably valid and most closely approach the observed values for the larger waves, which is to be expected since large waves are less susceptible to any kind of perturbation. The first line in the table, referring to a moderate wind velocity of 25 mph and a correspondingly small wave, shows a significant deviation of the observed from the calculated values. It seems, therefore, that although they are valid for strong wind and large waves way offshore, these relations must be somewhat modified to apply to more moderate wind and smaller waves—the characteristics of coastal waters.

Waves in Coastal Waters (30–200 Feet Deep)

From data obtained in measurements in 30- to 200-foot water nearer the shore, it appeared possible to extend equations (10) to (13) in order to cover these different conditions. The new relations are

$$v = (3.4 \pm 0.2)\, t = (0.74 \pm 0.02)\, w, \tag{14}$$

$$l = (2.6 \pm 0.4)\, t^2 = (0.12 \pm 0.03)\, w^2, \tag{15}$$

$$h = (1.5 \pm 0.3)\, t = (0.32 \pm 0.05)\, w, \tag{16}$$

$$w = (4.6 \pm 0.2)\, t. \tag{17}$$

TABLE 2. Correlation of Wind and Waves in Coastal Waters.

w in mph	v in mph		h in feet		l in feet		t in seconds	
	obs.	calc.	obs.	calc.	obs.	calc.	obs.	calc.
10		7.2-7.6	2.8	2.7-3.7	10-12	10-15	2.4	2.2-2.4
12	10	8.6-9.0	3.0-3.5	3.2-4.2	10-20	14-22	3.0	2.6-2.9
14		10.1-10.4	4.0-5.0	3.7-4.7	25-30	17-26	5.5	3.1-3.4
16		11.5-12.0		4.5-4.8	30-35	25-35		3.5-3.8
18	13	13.0-13.5	4.5-5.0	4.9-5.8		35-50	4.2	4.0-4.3
20		14.4-15.0	6.0-7.0	5.4-7.4	55-55	40-60	4.5	4.4-4.6
22		15.8-16.5	6.0-8.0	6.0-8.1	60-70	48-72	5.0	4.8-5.5
24	16	17.3-18.0	8.0	6.5-8.8		57-85		5.3-5.8
26		19.0-20.0	7.5-9.0	7.0-9.5	70-80	67-100	5.5	5.7-6.2
28		21.0-21.5	7.5-9.5	8.0-10.0		79-120	6.0	6.0-6.7
30		22.8	9.5-10.0	9.0-12.0	115	90-135	6.0	6.4-7.2

The summarized results of the measurements in coastal waters, together with the predicted values obtained from these empirical equations, are given in Table 2. As far as could be determined, equations (14) to (17) hold with reasonable accuracy under the following conditions:

1. The wind must blow for more than 1 hour without changing in intensity or direction, and without being hindered by dunes or other obstacles.

2. There must be no coastal current or strong tide interfering appreciably with the waves produced by the wind.

If these conditions are fulfilled, equation (16) permits the prediction of the average height of the waves as a function of the wind velocity. This is shown graphically in Figure 17, with the two dotted lines representing the calculated limiting values, and the points showing some of the measured values. Similarly in Figure 18, wave height is shown as a function of wave period. Since w and t can be rather easily measured, the two graphs provide a method of predicting wave height.

Figure 19 illustrates the combination of these relationships, with equation (16) used for moderate wind velocities – 0 to about 30 mph – in coastal waters, and equation (13) for higher wind velocities – about 25 to 50 mph – in deep water.

19.5.4 Conclusions

Two sets of equations have been found useful in predicting wave height from wind velocities over a range of 10 to 50 mph with reasonable accuracy. One set of equations, previously established by earlier work for large waves in deep water offshore, gives values corresponding closely with observed values obtained in this study. Another set of equations empirically established in this investigation for smaller waves in coastal waters was found to yield satisfactory predictions of the limiting values of wave height.[41]

Chapter 20

SPECIAL PROJECTS

20.1 10-TON MISSILE[a]

Summary

IN AN attempt to develop a large missile which could be used to destroy main Japanese fleet units at anchor and to breach Japanese dams, a 10-ton bomb was designed for delivery by means of a B-17 Flying Fortress bomber. The bomber may be operated by a skeleton crew or equipped with television and operated by remote control from a B-29 Superfortress bomber flying beyond range of enemy fire.

Plans for these devices, together with the results of scale tests, were presented to the U. S. Navy in July 1944 and to the Army Air Forces in September 1944. The project was abandoned, however, because of lack of interest by the using branches of the Armed Services.

20.1.1 The Problem

In the summer of 1944, with the Japanese fleet reluctant to leave port and with invasion of the Japanese home islands imminent, the director of the Office of Scientific Research and Development [OSRD] requested an investigation of methods which could be used to destroy main enemy fleet units lying in harbors and to attack certain important enemy dams.[b]

20.1.2 Procedure

A preliminary consideration of available low-angle glide bombs and small drones showed that these devices could not deliver an effective one-shot charge, and on a multiple-shot, "dry" hit basis would be subject to the disadvantage of relatively low velocity. The available evidence on successful operation for aerial homing devices was not impressive.

Attention was therefore centered on the possibility of using very large drones, each carrying a massive charge and controlled from a large "shepherd" plane by means of television, radar, and related devices. As an alternate plan, in view of the probable complications and delays involved in attempting to deliver a single large charge by a drone, a study was made of the possibility of delivering the charge in a low-altitude surprise attack with a stripped plane carrying a minimum crew and using a low-level bombsight.

FIGURE 1. Scale model of proposed Egg missile.

A study of the effect of attacks on capital ships showed that no non-armor-piercing missile large enough to destroy a battleship was available, and that a single charge of not less than 6 to 7 tons of explosive would be required. From available evidence, which was confusing and controversial, it appeared that an 8-ton charge would be capable of sinking or very seriously damaging a modern battleship. If the charge exploded below the target, the resulting force might well break the back of the ship.

In detonating a given mass of charge in an attempt to sink a ship, it was accepted as generally true that a "wet" hit is more effective than a "dry" one, for the shock waves are more effectively transmitted by water and the lower portion of the hull is usually more vulnerable. (An obvious exception is the case of the charge which penetrates the deck armor and explodes inside the ship, but this requires armor-piercing properties and presumably limits the size of the charge.) These considerations lent special attractiveness to a low-level attack with a single large charge so delivered and so fused as to give a low "wet" hit, and this was made the basis for the design of the missile.

[a] Project "Egg."

[b] This investigation was supervised by a representative of Division 12 of NDRC, assisted by the Applied Mathematics Panel and the Douglas Aircraft Corporation and conducted largely by the California Institute of Technology, Pasadena, Calif.

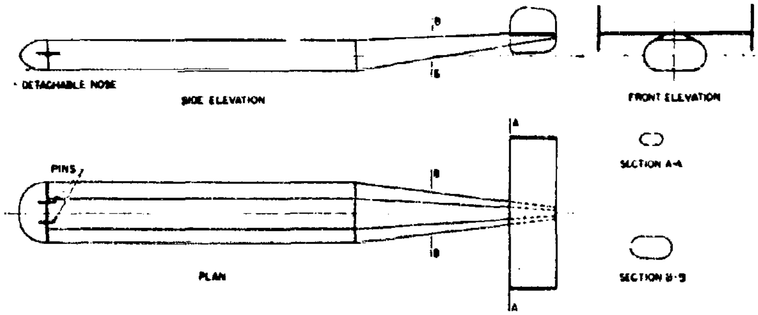

Figure 2. Schematic layout of Egg missile.

20.1.3 Results

The Missile

The missile designated as the Egg is a bomb carrying a 20,000-pound charge in a body 22 feet long, consisting of a cylindrical section 44 inches in diameter and 6 feet long, and followed by a frustum of a cone 16 feet long with a diameter of 21 inches at the small end (Figures 1 and 2). The bomb is provided with a detachable nose fairing, tail fairing, and stabilizing surfaces, making the over-all length about 35 feet.

The nose fairing is needed to avoid flow separation at the sharp edges on the front of the charge and to prevent high drag and doubtful stability. The fairing would be built of thin or brittle material so that it would break up on impact with the water and not influence the underwater characteristics of the charge. The tail would likewise break off on contact with the water. Its purpose is to guide the bomb into the water at an angle within the limits necessary for proper underwater trajectory. Stability in pitch is provided by a horizontal tail, and stability in yaw by twin vertical tails mounted at the tips of the horizontal stabilizers.

Several models of this design were built to a scale of 1:32 and tested for stability and for type of underwater trajectory. These indicated that a full-scale unit could be built so that, at an entrance velocity of 300 to 400 fps, it would slow to 200 fps in 65 feet of underwater travel, and would travel 200 to 225 feet under water at a maximum depth of orbit of 50 feet for a 17½-degree entry angle. The orbit would not be appreciably affected by pitch angles of entry of ±2 degrees. The trajectory would not be affected by shallower entry angles as small as 12 degrees, but, for larger entry angles up to 22 degrees, the maximum depth of orbit might be slightly increased beyond 50 feet.[5]

A survey of facilities available to the California Institute of Technology showed that California manufacturers, with stock in hand and without priorities, could deliver substantial numbers of Egg missiles in 60 days.

The Missile Carrier

The B-17 Flying Fortress bomber can be readily modified to carry the 10-ton missile designed for this project (Figure 3). It would be stripped of all unnecessary equipment, particularly the turrets and the turbosuperchargers. The power plant could be modified to give more power by incorporating a water injection system with water tanks, water pumps, and carburetor de-enrichment devices, and by adding jet exhaust stacks and one or more gas turbines in the rear of the fuselage.

Without armament or turbos, but with the 10-ton missile attached, the B-17 would require about 18,000 pounds of fuel for an 1,800-mile absolute range at 85 per cent rated power at 10,000 feet. This would give an average speed of approximately 210 mph and a take-off weight of approximately 72,000 pounds. The take-off distance to a 50-foot height would be approximately 6,000 feet with 1,800 bhp for take-off.[4]

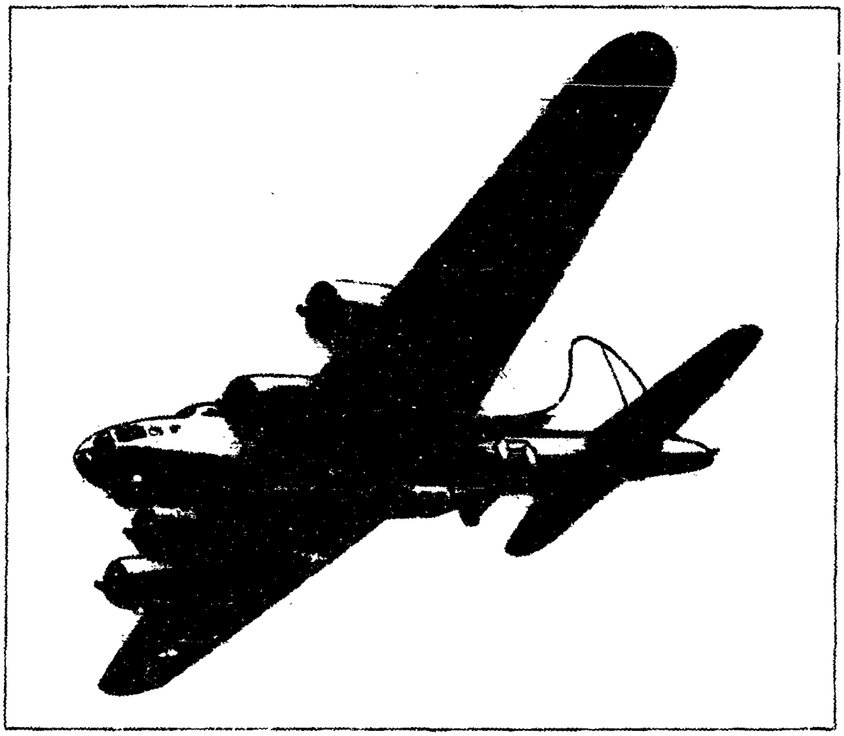

Figure 3. Egg missile in place under B-17 Flying Fortress.

Use Against Ships

The delivery of the Egg is visualized as a minimum altitude attack—perhaps from 100 to 300 feet above sea level—by a cleaned up B-17 manned by a two-man crew. It is not planned as a suicide mission. Instead, the specification of a small crew connotes that armament has been exchanged for speed and pay load. It would be used in a surprise attack, or in a task force-supported operation in which smoke and other anti-flak techniques are used to get the B-17's in and out again.

In a surprise attack, the aircraft would have sufficient fuel to reach a surface rendezvous, perhaps with a submarine, or to return to base. In an attack made in concert with a task force, the aircraft can rendezvous with units of the force.

For attacks in which visibility is adequate, the low-altitude, angular-rate Mark 23 bombsight is suggested, since it can presumably establish the point of entry with a probable error of approximately 25 feet. If the target is not visible, a simple radar bombing aid would be used.

As an alternate method, the Egg could be delivered in a B-17 under remote control of a "shepherd" plane, such as a B-29 Superfortress bomber. This would require equipping the B-17 with suitable television and remote-control devices, and although many if not all of the essential items could be obtained

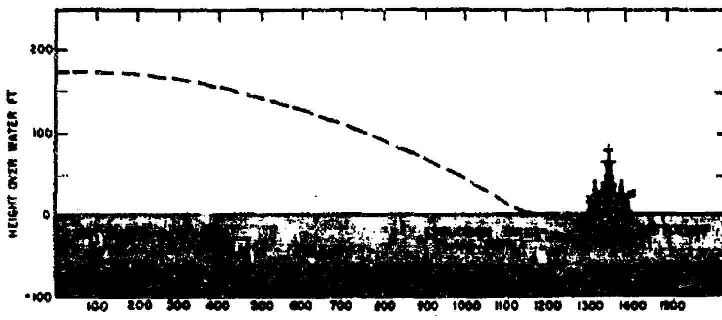

Figure 4. Path and site of explosion of proposed Egg missile.

quickly, a considerable and lengthy development would be involved in joining them into a dependable operating system.

As another alternate method, consideration was given to the possibility of having the remote-controlled B-17 crash into the ship's side, with the charge exploding immediately as a "dry" hit or, after the wreckage of the B-17 had sunk, with the bomb going off under water as a "wet" hit. This plan was not recommended because of the limited effectiveness of such a "dry" hit, the complications involved in transforming this into a "wet" hit, and the added vulnerability of the B-17 to enemy antiaircraft fire.

In the first two proposals, it is planned to fuse the bomb so that it would explode only after it had struck the ship's side and sunk to a point below the target's keel (Figure 4). In such a position, the effect of the charge would reach its maximum.

Use Against Dams

The Egg would be used similarly in attacks against a dam, with the expectation that a contact explosion of the 10-ton bomb would produce a 20-foot crater in the wet face. An extrapolation based on experience with earth-backed fortifications indicates that the tensile and shear strengths of a dam may be exceeded if the Egg is detonated within about 40 feet of the dam face at a depth of about 10 feet, the water level being within 10 feet of the top.

On the basis of the British attacks on the Moehne dam in Germany, it appears that the proposed 10-ton missile would be more practical. The British bombs had to be dropped within a 30-foot space to give a successful and not premature detonation. Because of the long underwater travel of the Egg, it would have to be dropped within a 150-foot space.

A high-altitude attack does not seem to be feasible for attacks on dams.

Use of Other Missiles

Although none would fill the requirements of a single-charge destructive missile, several devices may be investigated further. These include the AZON converted to an armor-penetrating projectile; low-angle glide bombs; and ROC and RAZON modified for shaped charges or for armor penetration.

30.1.4 Conclusions

Although no final recommendations could be made on the relative merits of high- and low-altitude bombing, or of one-shot attacks, it appeared from this preliminary study that the 10-ton missile should be developed and tested, and that the associated problems, including mounting and release mechanisms, optical and radar low-level bombsights, and the physical characteristics of the explosive to be used, should be investigated with all possible promptness. The alternate method of equipping a plane for remote-control delivery of the Egg should likewise be examined in more detail. Investigations should be

continued on the modification of existing smaller missiles for this particular objective.

20.2 JOINT PROJECTS

In May 1943, the Army and Navy jointly requested NDRC to investigate navigational aids which could be used in landing operations and to study methods for the demolition of obstacles to such operations. The Chairman of NDRC appointed personnel of Division 12 to serve with Committee NALOC (Navigational Aids for Landing Operations) and Committee DOLOC (Demolition of Obstacles to Landing Operations), set up to meet this military request. The work of these *ad hoc* committees is summarized in the final reports submitted by them.

In the development of the atomic bomb under the Manhattan Project, Division 12 was represented by Hartley Rowe, Chief of the Division, who was appointed consultant to the Chairman of NDRC for duties with the director of the research laboratory at Los Alamos, New Mexico, and by Roger S. Warner, Jr., technical aide of Division 12 and later attached to Division 5, who was appointed to aid in developing, engineering, assembling, and testing the atomic bomb. Later Warner was sent to the Pacific theater to assist in assembling the bomb that was dropped on Nagasaki and was present as an observer aboard the B-29 that dropped the bomb.

20.3 TRANSFERRED PROJECTS

Early in the history of NDRC, several projects were assigned to or initiated by Division 12 or its antecedents, Sections C-2 and C-5, and later, after NDRC reorganizations, transferred to other divisions or to the Armed Services. Final reports will be found in the summary reports of those divisions. These projects included the following:

1. A magnetic compass developed for use in tanks and other vehicles.[d]
2. An odograph developed largely as the result of research on the magnetic compass.[d]
3. Methods to protect tanks against antitank land mines.[d]
4. An ultrasilent, gasoline-driven electric generator which could not be heard in operation at a distance of 200 yards.
5. The development of a group of infrared devices.[e]
6. The development of a small, portable, rugged device requested by the Corps of Engineers for use in the field to make quick, accurate reproductions of maps. A survey of all available processes by Division 12 led to the selection of the manufacturer[f] who appeared best suited to conduct this investigation. This project thereafter operated under direct control of the Army, and no report of any results was reported by NDRC.
7. Plans for added defense against the night bombing of Britain by the enemy. It was proposed by Division 12 that a certain proportion of antiaircraft guns be devoted during an attack to fire haze-making shells. Then, by disposing upward-directed parachute flares within and below the haze, it would be possible to silhouette the enemy aircraft against a luminous background for attack from above, and, by placing downward-directed parachute flares above the enemy planes, to silhouette them for attack by antiaircraft fire from the ground. In order to prevent burning the shroud lines of the parachute flares, it was recommended that the flare be mounted on top of the parachute, probably being held in place by means of a suitable counterweight.
8. Plans made early in World War II for long-range attacks on the Japanese Fleet by means of a television-equipped, glider-borne aerial torpedo to be towed and radio-controlled by heavy bombers.[g]

[c] Projects AN-2 and AN-9, Manhattan Project.
[d] Summary Technical Report, Division 17, NDRC.
[e] Summary Technical Report, Division 16, NDRC.
[f] Charles Bruning Company, Inc., Chicago, Illinois.
[g] Summary Technical Report, Division 5, NDRC.

GLOSSARY

A-FRAME A two-legged lifting device held in position by guy wires.

AAF United States Army Air Forces.

AEF Allied Expeditionary Force.

AFAF Amphibious Forces, Atlantic Fleet, United States Navy.

AFHQ Headquarters, Allied Forces.

AFPF Amphibious Forces, Pacific Fleet, United States Navy.

AFTER BREAK The wall of broken water resulting from the collapse of a comber when it reaches shoal water.

AGF United States Army Ground Forces.

AKA Attack Transport (slope).

ALLIGATOR (ROEBLING) Early tracked amphibious vehicle.

AMPHIBIOUS JEEP ¼ ton 4x4 amphibious truck.

AMTRAC See LVT(s).

ARK M-29C amphibious Weasel.

ASF United States Army Service Forces.

BACKSTAY The rear stay of a mast.

BALK A support in the form of a transverse beam.

4.5 BBR 4.5 inch beach barrage rocket.

7.2 BBR 7.2 inch beach barrage rocket.

BHD Bulkhead. A wall to form a [illegible] compartment in a vessel.

BITT A fixed deck fitting for securing lines.

BLONDIN A cable that supports a [illegible] with the [illegible] of kites and drogues the [illegible] in a vertical position when moving through the water.

BOGIE In a track propelled vehicle [illegible] through which weight is transmitted to the track.

BOW CELL Watertight compartment attached to the bow to increase buoyancy.

BOW SCOOP In a track propelled amphibian [illegible] added to the standard bowblock [illegible] around the track.

BOW WAVE Characteristic wave produced in water [illegible] particular structure of a shape or amphibian [illegible].

BOW WING In a track propelled amphibian [illegible] water off the forward end of the return track [illegible] of the sprocket and to [illegible].

BOWBLOCK In a track propelled amphibian [illegible] placed at the forward end of the return track for the purpose of changing the direction of the water leaving the return track.

BRAIL A line for gathering up a sail or other canvas or a net. To gather up a sail or net.

BROACHED Turned broadside to the sea in such a manner as to be in danger of swamping.

BUFFALO See LVT(s).

c Cycles per second.

C Degrees centigrade.

CAPSTAN A cylindrical winding device with a perpendicular axis.

CARGO BOW Support for tarpaulin covering cargo compartment.

CATAMARAN A device in which two hulls are held together side by side in order to gain additional flotation and stability.

CAVITATION The formation of voids or cavities when the propeller is turned at such a speed that the water is discharged faster than it can flow into the propeller.

CCKW General Motors Corporation 2½ ton 6x6 truck.

CENPAC Central Pacific Command.

CHINE In [illegible] construction of a certain type of vessel, the edge formed at the intersection of the bottom and side of the vessel.

CHORD In bridge building, the upper and lower members of a truss.

CINCPAC Commander in Chief, Pacific Fleet, United States Navy.

CIT California Institute of Technology.

COIR A stiff [illegible] fiber made from the outer husk of the coconut.

COMINCH Commander in Chief, United States Navy.

CONVERSION DESIGN Design of an amphibian based on [illegible] conversion of [illegible] land vehicle [illegible].

CRONIC BARS [illegible]

DEADLINED Not operating.

DEADMAN [illegible]

DECK SCUTTLE A small opening in a deck [illegible] compartments below deck.

DEFOR [illegible] Operations [illegible] NDRC.

DROGUE A [illegible]

DUCK FERRY [illegible]

DUKW General Motors Corporation [illegible] amphibious [illegible].

EAC [illegible]

GLOSSARY

E.G. Project for development of 10 ton missile for long range airborne attack against enemy ships or dams

ENERGETIC TRACK PROPULSION. In a track propelled amphibian, track propulsion with the return track out of water

ESR. Engineer Special Brigade [illegible]

ETO. European Theater of Operations

F. Denotes Fahrenheit

FENDER. Bumper made of soft material, used to cushion the shock when a vessel strikes another object

FOOTROPE. A rope along the lower edge of a sail or net

FOREFOOT. The sharp section of the bow at the water level

FORESTAY. Forward stay for a mast

FREEBOARD. The height of the hull remaining above the waterline

G-3. Plans and Training Division of a headquarters

G-4. Supply Division of a headquarters

GMC. General Motors Corporation

GRADE ABILITY. Limiting angle of climb.

GROUND UP DESIGN. Design of an amphibian based on a completely new arrangement of components, not a conversion of any existing land vehicle or marine craft

GROUSER. In a track propelled vehicle, a structure secured to the track to improve propulsion.

GUEST WARP. A heavy rope hung over the side of the ship along the length of its hull to provide a means of mooring small craft

HEADROPE. A rope along the upper edge of a sail or net

HELL CAT. 76 mm gun motor carriage

HIGGINS BOAT. See LCVP

HOG TROUGH. A chute for discharging cargo by hand over the side of a DUKW

HOPPER. A man who assists a DUKW driver at shipside in mooring and loading cargo into the DUKW

HQ. Headquarters

IDLER. In a track propelled vehicle, a wheel which serves merely as a support for a track and does not transmit power to it

J. [illegible] placement

JANET. Joint Army Navy Experimental and Testing Board

JET REACTION. Reaction in the propulsive force of a jet

JCS. United States Joint Chiefs of Staff

JEEP. ¼ ton [illegible] truck

KEEL. Device used to hold torpedo net [illegible] distance from ship

LCM. Landing Craft Mechanized

LCM(3). Landing Craft Mechanized, Mark 3

LCT. Landing Craft Tank

LCT(5). Landing Craft Tank Mark 5

LCT(6). Landing Craft Tank Mark 6

LCV. Landing Craft Vehicle

LCVP. Landing Craft, Vehicle, Personnel (Higgins Boat)

LEECH ROPE. A rope along the trailing edge of a sail or net.

LOA. Over-all length

LSD. Landing Ship, Dock.

LSM. Landing Ship, Medium

LST. Landing Ship, Tank (United States built)

LST(1). Landing Ship Tank Class 1 (British built)

LSV. Landing Ship, Vehicle

L. T. Length of track on ground tread

LUFF ROPE. A rope along the leading edge of a sail or net

LVT. Landing Vehicle, Track

LVT(1). Landing Vehicle, Track Mark 1.

LVT(2). Landing Vehicle, Track Mark 2

LVT(3). Landing Vehicle, Track Mark 3 (Buffalo).

LVT(4). Landing Vehicle, Track Mark 4 (Amtrac)

LVT(A). Landing Vehicle, Track (Armored)

LVT(A)(1). Landing Vehicle, Track (Armored) Mark 1

LVT(A)(2). Landing Vehicle, Track (Armored) Mark 2 (Amtank).

LVT(A)(4). Landing Vehicle, Track (Armored) Mark 4

LVT(A)(5). Landing Vehicle, Track (Armored) Mark 5

LWL. Waterline with vessel loaded

MTER. Motor transport engineering request for changes (General Motors Corporation)

MTO. Mediterranean Theater of Operations

NALOC. Navigational Aids to Landing Operations Committee, NDRC

NDRC. National Defense Research Committee

OA. Over all

ORDD. United States Army Office of Chief of Ordnance, Detroit, Michigan

OFS. Office of Field Service, OSRD

105. 105 mm howitzer

OSRD. Office of Scientific Research and Development

PELICAN. Amphibious cargo carrier with payload greater than 2½ tons

POA. Pacific Ocean Area

PROPELLER PITCH RATIO. Ratio of diameter of the blade to pitch of the blade

PROTECTOSCOPE. In tanks, a built-in periscope-like device designed to permit indirect vision while protecting the observer from enemy gunfire.

QUARTERING SEAS. Seas approaching at an angle of approximately 45 degrees from the stern.

RAKE FRAMING. Framing not square to the line of the keel, such as occurs at the bow and stern of most vessels.

RASC. Royal Army Service Corps (British).

RESERVE BUOYANCY. Amount of buoyancy remaining after loading.

R. T. PLATE. Road-tread plate.

RIPPLE FIRE. Fire given in rapid sequence.

RITCHIE DEVICE. Auxiliary metal pontoons for tank flotation.

RUB RAIL. Rail along the outer side of the hull, installed to protect the hull sides themselves from damage in contact with other objects.

SCORPION. Mobile rocket launcher.

SCHUSS. Downhill run on skis.

SCOUR HOLES. Holes cut in the face of a coral reef by action of the sea.

SEABISCUIT. Project for development of ice chain to protect tanks against antitank mines.

SEAC. Southeast Asia Command.

SEETING SUN. Project for development of long-range glider-borne remote-controlled torpedoes.

SHROUD. The side stays of a mast.

SKIRT HOLES. In a track-propelled amphibian, various sizes and arrangements of holes in the track skirt along the line of the rear track tunnel above and below the track, and at several stations along the track.

SNAKE. Project for development of jet-propelled amphibious demolition charge.

SOPAC. South Pacific Command.

SOWESPAC. Southwest Pacific Command.

SPRING LINES. Lines used in mooring a vessel so rigged that those lines attached to the bow lead aft, and those attached to the stern lead forward.

STEEP-TO BEACH. Beach shelving sharply into deep water.

STERN CELL. Watertight compartment attached to the stern to increase buoyancy.

STERN SCOOP. In a track-propelled amphibian, a device similar to a standard bowblock mounted around an idler at the after end of the track.

STERN STRIPPING. In a track-propelled amphibian, stripping of the water at the rear idler by means of a vertical plate tangent to the track as it passes around the idler.

STERN WING. In a track-propelled amphibian, a device to strip water off the stern end of the return track and to turn it 180 degrees outboard and astern.

STRIPPER PLATE. In a track-propelled amphibian, a plate installed tangent to the track to strip the flow of return water.

SUBMERGED TRACK PROPULSION. In a track-propelled amphibian, track propulsion with all tracks under water.

SURF PLATE. A plate on the bow of a vessel to deflect spray.

TC. United States Army Transportation Corps.

T/E. Table of Equipment (United States Army). List which describes the equipment officially authorized for an Army unit.

TND. Torpedo net defense.

T/O. Table of Organization (United States Army). List which describes the personnel officially authorized for an Army unit.

TRACK SKIRTS. In a track-propelled amphibian, extensions of the hull outboard of the track, forming with the sponson and hull a tunnel in which the return track operates.

TURRET. Project for development of improved land combat vehicles; series of proposed improved land combat vehicles.

VISION BLOCK. In tanks, a thick glass window constructed to give direct vision and at the same time provide maximum protection against enemy fire.

VISION CUPOLA. In tanks, a cupola designed to accommodate one or more vision blocks, generally located over the head of the tank commander or driver.

WDGS. United States War Department General Staff.

WEASEL. Track-laying light cargo carrier.

WET FERRY. Ferrying with load partly submerged.

WL. Waterline.

WT. Watertight.

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Chapter 20

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6. *The Effect of Roughness of Sea on the Entry Angle of a Projectile* (Morris Dam report No. 127), R. I. Piper, OEMsr-418, California Institute of Technology, Pasadena, Calif., August 18, 1944. Div. 12 2000 M6

OSRD APPOINTEES

Division 12

Chief

Hartley Rowe

Deputy Chief

Ralph Douglas Booth

Technical Aides

James A. Britton	Palmer Cosslett Putnam
S. Murray Jones	Roger Sherman Warner, Jr.

Members

Kenneth S. M. Davidson	Henry E. Rossell
[illegible] M. Goldsmith	Richard Henry Whitehead
Eugene James Reardon	William L. Woodward

Section 12.1

Chief

William Frederick Durand

Members

James L. Bates	Ernest Rea
William Hovgaard	Karl Ernest Schoenherr

CONTRACT NUMBERS, CONTRACTORS, AND SUBJECT OF CONTRACTS

Contract Number	Name and Address of Contractor	Subject	Refer to Chapter
NDCrc-41	Carmack & Carson, Philadelphia, Pa.	Investigation of design problems in connection with trestle bridges, portable bridges, portable overpasses, ponton bridges, and other Engineer Corps structures.	12
NDCrc-148	National Research Council, Washington, D. C.	Development of a wheel brake drum and brake lining combination which will permit more energy to be absorbed per unit of rubbing surface. Development of improved disk brakes.	18
NDCrc-201	United Shoe Machinery Corp., Boston, Mass.	Development and design of a gun turret for light and medium tanks.	16
OEMsr-26	Edgerton, Germeshausen & Grier, Cambridge, Mass.	Development and study of high speed pictures of direct mechanisms.	17
OEMsr-36	Sparkman & Stephens, Inc., New York, N. Y.	Preliminary studies of ferries, barges, and pontoons.	14
OEMsr-41	Drexel Institute of Technology, Philadelphia, Pa.	Investigation of design problems in connection with trestle bridges, portable bridges, portable overpasses, ponton bridges, and other Engineer Corps structures.	11 12 13
OEMsr-72	American Steel & Wire Co., New Haven, Conn.	Investigation and development of a pneumatic tire substitute.	18
OEMsr-112	United Shoe Machinery Corp., Boston, Mass.	Investigating improved tank vision devices.	16
OEMsr-133	The Sharples Corp., Philadelphia, Pa.	Design, development, and testing of a centrifugal cleaner for carburetor intakes to improve operations of tanks during sand storms. Development of testing techniques with particular reference to particle size.	16
OEMsr-138	[illegible], Pittsburgh, Pa.	Investigation of design problems in connection with pontoon bridges.	12
OEMsr-151	Sparkman & Stephens, Inc., New York, N. Y.	Design, development, construction, and testing of a $2\frac{1}{2}$-ton amphibious jeep, a[illegible] amphibious and [illegible] platform track [illegible] [illegible] vehicles (Weasel), the $2\frac{1}{2}$-ton amphibious truck (DUKW), a trailer for $2\frac{1}{2}$-ton amphibious truck, and [illegible] related equipment, including engineering and consulting services connected therewith. Development of an amphibious vehicle which can be used for transport over swamps and mud flats. Design of various models of [illegible] to be designed or converted for amphibious use. A study of [illegible] properties. Investigate present rafts and salvage designs of proposed modifications of existing rafts and completely new designed rafts which will hold survival equipment as required for the personnel while living on the rafts and which will incorporate such additional comforts for the personnel as is possible without exceeding weight limitations.	2 3 4 5 6 7 8 9 10 18
OEMsr-182	Marmon-Herrington, Indianapolis, Ind.	Development, construction, and testing of $\frac{1}{4}$-ton amphibious jeep.	[illegible]
OEMsr-215	Carmack & Carson, Philadelphia, Pa.	Investigation of design problems in connection with trestle bridges, portable bridges, portable overpasses, ponton bridges, and other Engineer Corps structures.	12
OEMsr-436	National Research Corporation, Boston, Mass.	Study of methods for overcoming the effects of fog, rain, sleet, frost, ice, dust, and other deposits upon optical and other transparent surfaces.	18

CONTRACT NUMBERS, CONTRACTORS, AND SUBJECT OF CONTRACTS
(Continued)

Contract Number	Name and Address of Contractor	Subject	Refer to Chapter
OEMsr-158	Trustees of the Stevens Institute of Technology, Hoboken, N. J.	Construction of testing tank and investigation of effect of various changes of hull form and loading on turning of ship models and Navy vessels.	10
OEMsr-460	General Motors Corporation, Detroit, Mich.	Study of noise reduction in tanks.	17
OEMsr-391	The Ford Motor Co., Dearborn, Mich.	Development and construction of ultra silent motor generator.	20
OEMsr-467	The Ford Motor Co., Dearborn, Mich.	Development, construction, and testing of ¼ ton amphibious jeep.	2
OEMsr-497	Jones & Lamson Machine Co., Springfield, Vt.	Development of [illegible] inspection method to eliminate the use of thread, plug, and ring gages. Development of methods of thread gaging which will eliminate the use of thread, plug, and ring gages or which will minimize wear resulting in rapid deterioration of the gage as a precision instrument. Assembly of a comprehensive bibliography of screw thread gage theory, practice and instruments. Development of one or more models of such gaging equipment. Printing and developing (500) copies of a monograph on manufacturing methods for the production of plug and ring gages.	18
OEMsr-524	Baker Manufacturing Company, Evansville, Wis.	Design, development, construction, and test of one or more full scale pilot models of combat vehicles complementing established and proved characteristics with the most advanced principles of design and development which may result from collaboration between interested branches of the Armed Services and leading technical, scientific, and industrial personnel.	5 17
OEMsr-588	[illegible], Pittsburgh, Pa.	Investigation and development of a permanent tire substitute.	18
OEMsr-631	[illegible], New York, N. Y.	Investigation and development of a permanent tire substitute.	18
OEMsr-655	The Studebaker Corporation, South Bend, Ind.	Design, development, construction, and test of four full scale pilot models of amphibious airborne track laying snow vehicle and of two full scale pilot models of a nonamphibious airborne track laying snow vehicle, T-15 Weasel. Assistance in acquisition and study of snow data. Development and construction of four modified snow vehicles M-29 Weasel.	5 19
OEMsr-[illegible]	[illegible] Products Company, Dearborn, Mich.	Investigation and development of a permanent tire substitute.	18
OEMsr-[illegible]	William [illegible], Philadelphia, Pa.	Investigation and development of a permanent tire substitute.	18
OEMsr-[illegible]	[illegible], Detroit, Mich.	Investigation and development of a permanent tire substitute.	18
OEMsr-[illegible]	William [illegible], Houston, Texas	Investigation and development of a permanent tire substitute.	18
OEMsr-[illegible]	Vinyl Corporation, New York, N. Y.	Investigation and development of a permanent tire substitute.	18

CONTRACT NUMBERS, CONTRACTORS, AND SUBJECT OF CONTRACTS

(Continued)

Contract Number	Name and Address of Contractor	Subject	Refer to Chapter
OEMsr-802	James V. Martin, Rochelle Park, N. J.	Investigation and development of a pneumatic tire substitute.	19
OEMsr-870	GMC Truck & Coach Division, General Motors Corporation (formerly Yellow Truck & Coach Manufacturing Company), Pontiac, Mich.	Design, development, construction, and test of (1) one full scale pilot model of a $2\frac{1}{2}$-ton amphibious truck (DUKW); (2) one model of an amphibious trailer for use with the $2\frac{1}{2}$-ton amphibious truck; (3) installation of rocket launcher in DUKWs in accordance with general function specifications furnished by Division 3 of NDRC; (4) a tank lifting machine; (5) complete sets of accessory equipment for use of amphibious truck in ferrying tanks, other land vehicles and airplanes; (6) accessory equipment for use of the amphibious truck as a bridge ponton; (7) automatic tire inflation and deflation device; (8) bow and stern wake suppression machine for use with the amphibious truck; (9) three sets of H-10 Armored Force Treadway Bridge; and (10) assistance in study of bow and stern wake visibility and possible suppression. Performance of such other work on related equipment as may be requested.	3, 4, 17, 19
OEMsr-878	Polytechnic Institute of Brooklyn, Brooklyn, N. Y.	Development and study of snow data for the purpose of assisting in the design of snow vehicles, the possible forecasting of snow characteristics in theaters of operation, and the forecasting of vehicle performance in such theaters.	19
OEMsr-907	Kelsey-Hayes Wheel Company, Detroit, Mich.	Investigation and development of a pneumatic tire substitute.	19
OEMsr-930	Budd Wheel Company, Detroit, Mich.	Investigation and development of a pneumatic tire substitute.	19
OEMsr-1077	American Steel & Wire Company, New Haven, Conn.	Investigation of the design and operation of antitorpedo nets. Development of suitable counter-countermeasure methods. Delivery of improved designs of [illegible].	13
OEMsr-1106	The Studebaker Corp., South Bend, Ind.	Development of an amphibious vehicle which can be used for rescue work over swamps and mud flats. M-29C Weasel.	5
OEMsr-1182	F. L. Jacobs Company, Detroit, Mich.	Design and construct Van Patten disk propellers and run comparative tests with screw placed in craft installed by Navy.	18
OEMsr-1339	I-T-E Circuit Breaker Company, Philadelphia, Pa.	Studies and experimental investigations in connection with the modification of the present Mark VI bomb rack and development of a new bomb rack interchangeable with the Mark VI. Tests of such racks and such other related equipment as may be requested.	18
OEMsr-1344	Sparklets & Stephens, Inc., New York, N. Y.	Studies and experimental investigations in connection with [illegible] and propelling amphibious explosive charges.	[illegible]
OEMsr-1395	Douglas Aircraft Co., Inc., Santa Monica, Calif.	Studies and experimental investigations in connection with the modification of the present Mark VI bomb rack and development of a new bomb rack interchangeable with the Mark VI. Tests of such racks and such other related equipment as may be requested.	18
[illegible]	Hydraulic Research Institute, State University of Iowa, Iowa City, Iowa	Study of cavitation on water tank models.	18

SERVICE PROJECT NUMBERS

The projects listed below were transmitted to the Executive Secretary, National Defense Research Committee [NDRC], from the War or Navy Department through either the War Department Liaison Officer for NDRC or the Office of Research and Inventions (formerly the Coordinator of Research and Development), Navy Department.

Service Project Number	Subject	Refer to Chapter
AC-[illegible]	Survey and improvement of aircraft landing wheel brakes	18
AC-[illegible]	Study of methods for minimizing the effects of rain, fog, sleet, frost, ice, dust and other deposits upon optical and other transparent surfaces	18
AC-80	Development of amphibious vehicle for use in rescue work over swamps and mud flats	5
AN-[illegible]	Studies and investigation of [illegible] amphibious explosive charges	6
CE-1	Assistance in design and test of bridges and ferries	11, 12, 13
CE-20	Study of vehicle for use in demolition of key enemy held facilities and in their restoration by friendly troops	15
MC-101	Development of a trailer hitch	8
NE-101	Design, development, and testing of improved [illegible] lifeboat	16
NE-102	Design, development, and testing of improved sailing rubber boat	16
NE-158	Development of improved antitorpedo nets and development of suitable countermeasure methods	15
NE-150 Merchant	Study of requirements for sound devices for merchant ships and development of sonar detecting devices for merchant vessels	[illegible]
NO-234	Redesign of navy bomb racks Mark 51 Mods 6 & 7	18
NS-160	Design, construction and testing of [illegible] propeller	18
NS-201	Study of cavitation in water tank models	19
OD-[illegible]	Study of devices and methods for the reduction of tank noise	17
OD-[illegible]	Development and design of turret gun mount for armored fighting vehicles	16
OD-[illegible]	Development of centrifugal air cleaners	16
OD-[illegible]	Development of thread ring [illegible] method which will eliminate the use of thread plug and ring gages	18
OD-[illegible]	Design, development, building and testing of land combat vehicles	[illegible]
OD-[illegible]	Assistance in development and procurement of equipment and devices for field conversion of the M 3 tank to eliminate [illegible] difficulties	18
OD-[illegible]	Study of methods and devices for controlling the [illegible] of towed artillery gun carriages	[illegible]
OD-[illegible]	Design, development, construction and testing of [illegible] amphibians and [illegible] track laying [illegible] vehicles [illegible]	[illegible]
OD-[illegible]	Design, development, construction and testing of amphibious trailer for 2½ ton amphibious truck and of [illegible] amphibious trailer	[illegible]
OD-[illegible]	Design, development, construction and testing of portable rocket launcher for [illegible]	[illegible]
OD-[illegible]	Design, development, construction and testing of [illegible] amphibious [illegible]	[illegible]
OD-[illegible]	Investigation and development of [illegible]	18

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